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REQUIREMENTS STUDY FOR A BIOTECHNOLOGY LABORATORY FOR MANNED EARTH ORBITING MISSIONS

Volume I - Results, Recommendations and Requirements

by L. T. Kail

Prepared by
MCDONNELL DOUGLAS CORPORATION
Huntington Beach, Calif.
for

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PREFACE

This document contains the results of a study of the requirements for a biotechnology laboratory for manned earth orbiting missions in the 1970's. The results are presented in two volumes. Volume I contains descriptions of the life sciences research programs and the associated laboratory equipment requirements. The objectives and corresponding information needs of these research programs were prepared on the basis of the results of past studies and in collaboration with the NASA and the scientific community. While these objectives are not to be construed as an official statement by NASA of life sciences space research goals in the 1970's, they do represent a consensus developed under the cognizance of NASA OART, OSSA, and OMSF*. These goals served as a reliable basis for the selection of representative experiments in each research category and the subsequent establishment of laboratory equipment requirements. Volume II contains brief descriptions of the experiments upon which the requirements analysis was based.

The study has resulted in the identification of more than 100 major items of laboratory equipment which will be required in manned Earth-orbiting laboratory life science research programs. Many of these items were found to have multiple applications, while others are required only by a single experiment in a narrow research subcategory. In addition, an examination of the availability of the equipment showed that development programs of some magnitude will be required before the equipment

*National Aeronautics and Space Administration Office of Advanced Research and Technology, Office of Space Science Applications, and Office of Manned Space Flight.

will be suitable for space applications. The results of this study provide information to support the planning of the necessary equipment development programs as well as the life science research programs for individual missions throughout the 1970's.

The study was performed by the McDonnell Douglas Astronautics Company—Western Division (MDAC-WD) for the Biotechnology and Human Research Division of the Office of Advanced Research and Technology (OART). The work began in January, 1968 and was performed in accordance with contract number NAS7-518.

The work on this study was performed by MDAC-WD personnel from two departments: Advance Biotechnology and Power Systems, Dr. K. H. Houghton, Chief Engineer; and Advance Space Stations, F. C. Runge, Program Manager. The study was managed for NASA (OART) by R. W. Dunning, and for MDAC-WD by L. T. Kail.

Throughout the study, the MDAC-WD study team worked closely with NASA Headquarters personnel. The study team members and their NASA coordinators were:

Study Team	NASA Coordinator
Bioscience - Dr. W. H. Lawrence, Jr.	Donn K. Jenkins (SB)
Biomedicine - Dr. W. F. Arndt, Jr.	Dr. E. J. McLaughlin (MM)
Behavior - J. D. Brower	Dr. S. Deutsch (RBM)
Life Support Systems - T. C. Secord	A. L. Inglefinger (RBB)

Other MDAC-WD personnel who made significant contributions were J. S. Seeman in the area of Behavioral Research and M. M. Yakut in the area of Life Support and Protective Systems Research.

Questions or comments concerning this report will be welcomed by either of the individuals listed below:

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Section 1
INTRODUCTION

NASA has performed or sponsored many studies, the objective of which was the definition of life sciences research that must be performed before man can venture confidently into space. Other studies have explored that research which could take advantage of the unique weightless environment available in space missions to increase our understanding of life processes. This activity has included many studies in the various fields of life science and has resulted in the identification of various research objectives and the equipment needs of associated experiments. An examination of the results of these studies has indicated that extensive research and development would be required to provide the laboratory equipment needed to perform such life science research in Earth-orbiting laboratories. Since the individual studies performed to date have been limited to either a single life science field, or a part of that field, a need arose to develop a plan for an integrated program which includes all of the required research and takes maximum advantage of equipment commonality. The objective of the study presented here was to expand and incorporate the results of past studies, into an all-encompassing life science research program (gap-filling as required) to identify manned Earth-orbital life science laboratory equipment requirements for the 1970's. Another objective of the study was to identify and integrate requirements that are common to the four life science research fields of biomedicine and human research, behavior, bioscience, and life support systems.

To orient the reader, an elementary sketch of a concept for a biotechnology laboratory as part of a multipurpose space station is shown in Figure 1-1. The individual equipment items required in the "laboratory area" are described. The centrifuge shown relates to requirements of experiments considered in this report and represents another program currently under study by NASA for life sciences research. This study has addressed itself to the total research activities and equipment encompassed by such a laboratory. The results of the study provide a basis for further definition of a facility.

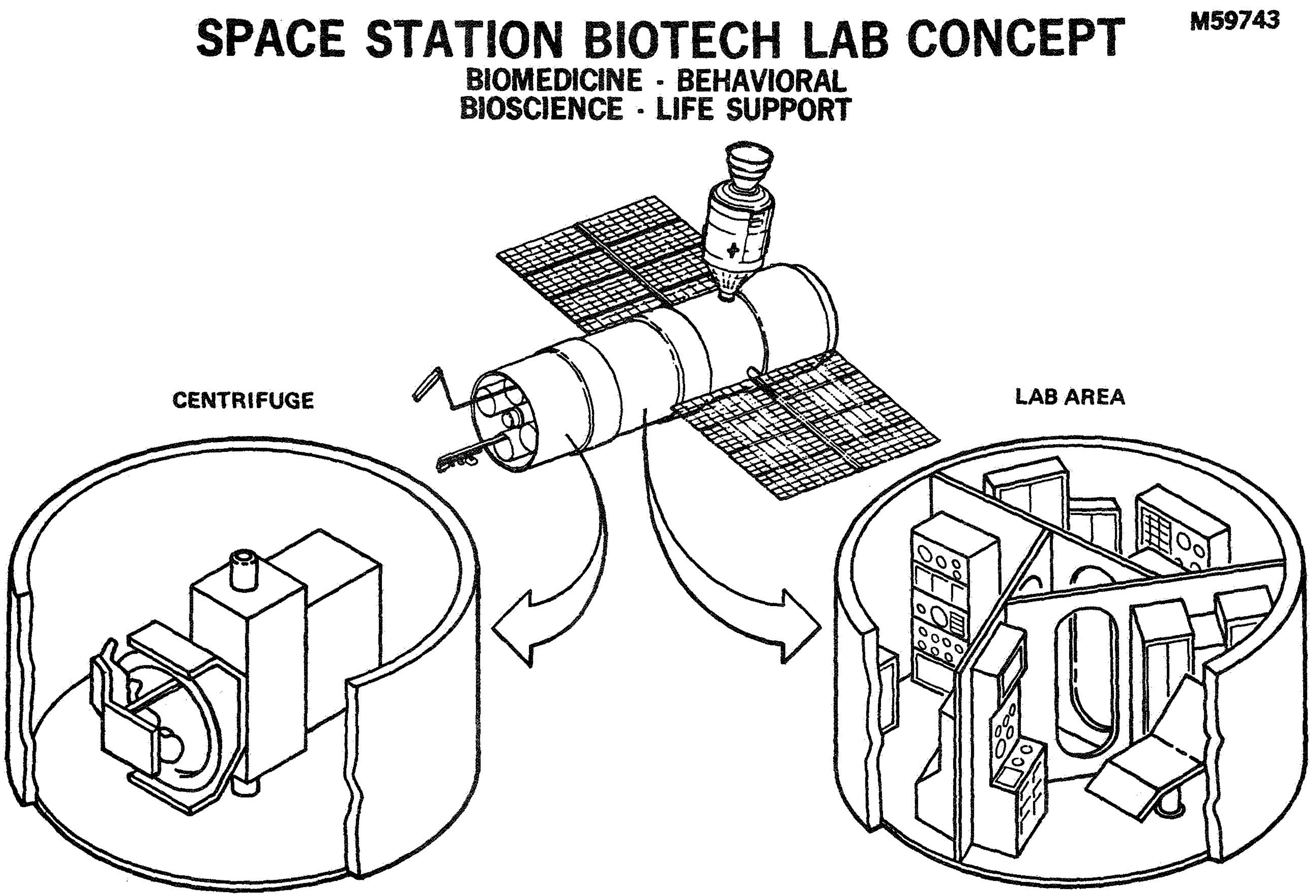

Figure 1-1. Space Station Biotech Lab Concept

In the preparation of this report MDAC has endeavored to provide a document which will be used as a reliable reference by personnel engaged in life sciences activities in space in particular, and by those involved in space program planning in general.

Program managers and mission planners are referred to the biotechnology research goals and the program recommendations in Section 3. The research and development requirements and the program planning suggestions in this section will be of particular value.

Research scientists who are interested in the detailed description of the research programs, and the methods by which they were assembled will find such information in Section 4. The manner in which a special field of research fits into the total research goals is also presented. The measurements associated with the experiments in each research subcategory are also discussed. Further details concerning each of the experiments is presented in the experiment summaries in Volume II.

Space laboratory design engineers and others concerned with planning and studying the accommodations of life sciences experiment programs in such laboratories will find complete lists of the required experiment equipment in the matrix charts in Section 5. The commonality of equipment which is graphically displayed in these charts will permit experiment program planners to modify the experiment programs to take advantage of equipment which has broad application. The power, weight, and volume requirements of each item of equipment, as far as they could be determined, are summarized in Section 7.

Supporting research and technology planners are referred to Section 7, in which each item of equipment requiring development is listed. Current development programs which include these items are identified where applicable. The matrix charts, showing the commonality of equipment throughout the experiment programs will assist in the selection of equipment which requires development emphasis.

The space station for the mid 1970's, in which a large portion of the research outlined herein will be performed, is currently in the candidate configurations study phase within NASA. Therefore, this document will provide a coordinated (OART, OMSF, OSSA)* reference for the forthcoming Phase B space-station studies and will ensure the proper integration and support of the biotechnology laboratory in the space-station configuration.

*Office of Advanced Research and Technology; Office of Manned Space Flight; Office of Space Science and Applications.

Section 2
STUDY APPROACH

The objectives of this study were (1) to correlate space-based life sciences research goals for the next decade and (2) to identify the laboratory requirements for conducting, in a manned orbiting space station, the experiments which are representative of that research.

In reaching these objectives, MDAC followed a modified version of the "top-down analysis" approach which was successfully used by the Company in recent NASA studies in astronomy, oceanography, and meteorology. The initial step in these previous studies involved the identification of the overall research objectives. This was followed by an examination of the objectives to define those which require or use space-based facilities. The final step was the development of an orbital experiment program which included the required instrumentation, facilities, and operational support.

The first objective of this study was accomplished by performing the first two steps during which we relied to a considerable extent on past NASA and contractor work. Since the reports dealt almost exclusively with space-oriented research, it was not necessary to review research objectives which were not space related. Further, the development of a representative orbital experiment program was accomplished by selecting, again from existing literature, the experiments which were considered to be responsive to the information needs of each research category. The analysis also indicated research requirements for which there were no proposed experiments. In these instances, the study team prepared possible experiments so that the required measurement equipment would not be overlooked.

In reaching the second objective of the study, MDAC analyzed the selected experiments to identify the necessary measurements, laboratory equipment, and support equipment and to ensure that the equipment requirements were indeed representative and responsive to the research needs.

An Experiment Requirements Summary was prepared for each experiment analyzed. Matrix charts which illustrate the commonality of measurements and the commonality of equipment were prepared for the representative experiments in each of the four research areas of biomedicine, behavior, bioscience and life support, and protective systems.

Each major item of required laboratory equipment was described briefly. In cases where equipment designed for space use could not be identified, the study team listed ground-based equipment in order to indicate the nature of the requirement.

At the end of the study, the MDAC study team made suggestions as to how the identified research programs might be carried out. Because the making of these suggestions involved the assignment of research priorities, the study team realizes that these suggestions are open to criticism. However, the intent of these recommendations is to provide a reference upon which future research in manned space missions may be based.

In summary, the approach to the study was based on four basic tasks:

1. Extracting research goals from existing life-science literature.
2. Structuring research programs.
3. Selecting experiments which are representative of these programs.
4. Identifying laboratory equipment required by the representative experiments.

The following sections present the detailed output of this effort.

Section 3
RESULTS AND RECOMMENDATIONS

The life sciences research program evolving from this study is summarized in this section to provide an overview of the total program scope before proceeding to the details of the individual areas (Section 4). In each individual area, consideration of the desirable sequence for performing this research has led to recommendations concerning the implementation of the biotechnology laboratory program. These recommendations are discussed in the second half of this section.

3.1 LIFE SCIENCES RESEARCH PROGRAM SUMMARIES

Briefly, the Life Sciences research goals defined for manned space missions are as follows:

1. Obtain an understanding of man's reaction to long-term exposure to the space environment.
2. Study the effects of the space environment on living organisms and increase our understanding of life on Earth.
3. Advance the technology for support of man in extended exposure to the space environment.

Research necessary to achieve the first goal is discussed under the separate headings "Biomedical and Human Research" and "Behavioral Research". Despite the intimate relationship between these two areas, they were treated separately to provide equal emphasis during the study and to permit ease of reference by specialists in each area. Under "Bioscience Research," the activities necessary to achieve the second goal are described. In "Life Support and Protective Systems Research," the research necessary to achieve the third goal is described.

The research programs prepared in this study form a firm base for planning space research in life sciences for at least the next decade. Results from the experiments described should answer most current pressing questions and raise others which, in turn, will give rise to further research.

There is no doubt that one of the most important current questions concern man's reaction to long periods in space; therefore, research in the areas of biomedical and behavioral research will receive the highest priority in mission assignment. Bioscience research which will study life processes in the weightless environment of an Earth-orbiting laboratory holds significant potential value in contributing to a fuller understanding of those life processes on Earth. The development of effective life support systems is, of course, the key factor in all space research programs involving man. This development requires not only system and component testing but also research in the associated basic technology. The ability of the crew to maintain this "hardware" system in the space environment, the reaction of the crew to the atmosphere provided, and the analysis of microbial products which may develop in the space station ecology require the facilities of an integrated laboratory if the life support system research is to be effective.

It is recommended that the biotechnology laboratory provide facilities for research from each of the areas of biomedicine, behavior, bioscience, and life support and protective systems.

3.1.1 Biomedicine and Human Research Program Summary

The biomedicine and human research program presented in this report is composed of 55 representative experiments on both human and animal subjects. The established program goal is to qualify man for long-duration space flight. The specific objectives within this goal are those stated by NASA and discussed in Section 4. By using these objectives as guidelines, it was possible to organize critical research areas or "information needs" which were identified in a variety of previous studies into 10 different functional body systems. Experiments which appeared to satisy the information needs were then selected and reviewed, and then were consolidated to achieve economy of operation. In a few cases where no experiments were located in the literature, protocols were specifically designed to fulfill the needs. Finally, each experiment was analyzed to determine the required measurements and equipment. Table 3-1 presents the basic organization of this biomedical program and shows the distribution of experiments.

was analyzed to determine the required measurements and equipment. Table 3-1 presents the basic organization of this biomedical program and shows the distribution of experiments.

Table 3-1

BIOMEDICAL-HUMAN RESEARCH STUDY PROGRAM OUTLINE

		Number of Experiments Man	Number of Experiments Animal
Neurologic function	Vestibular function	2	1
	Circadian rhythms	-	1
Cardiovascular function	Cardiovascular deconditioning	5	-
	Deconditioning countermeasures	3	-
	Homeostatic mechanisms	2	1
	Blood volume	1	-
	Verification of measurement techniques	-	1
	Vascular collapse	-	1
Pulmonary function	Ventilatory mechanics	2	-
	Pulmonary efficiency	1	-
	Pulmonary disease	-	3
Gastrointestinal function	Function and motility	2	-
Renal function	Renal physiology	1	-
	Renal pathology	-	2
Nutrition--metabolism	General metabolism	1	-
	Specific metabolites	4	-
Musculoskeletal function	Decalcification	1	-
	Work capacity	2	-
	Bone pathology	-	2
Endocrine function	Stress effects	1	2
	Thermal regulation	1	-
Hematological function	Cytogenetics	1	-
	Cell dynamics	3	2
	Coagulation	1	-
	Tissue pathology	-	1
Microbilogy and immunology	Ecology	4	-
	Totals	38	17

3.1.2 Behavioral Research Program Summary

The behavioral research program defined in this study was based on current and future NASA program requirements and a critical review and evaluation of the information needs, research categories, and experiments cited in the literature. In general, the literature concerned with measurement and evaluation of man's reaction and adaptation to the orbital environment and his ability to perform meaningful tasks for extended periods of time.

During the study, a structured approach was developed which consisted of the following:

1. Determination of information needs.
2. Establishment of research categories and description of experiments responsive to the information needs.
3. Development of a plan for implementing the research program.

The program is summarized in Table 3-2.

3.1.3 Bioscience Research Program Summary

The goal of the bioscience research program described here is to increase our understanding of biological mechanisms through the study of various life processes in the unique environment of a weightless, orbiting space laboratory. The program is composed of 50 experiments utilizing 19 different plant and animal subjects that vary in biological complexity from single-cell protozoa and bacteria to primates. This program was developed by selecting representative experiments from a variety of sources. The American Institute of Biological Science (AIBS) Report of December 1967 provided guidance in the matters of priority research areas and effective utilization of experimental subjects.

The entire program is designed for the performance of basic rather than applied research and is structured around nine research objectives. Of these objectives, seven were recommended by the AIBS report and two were added. For each research objective, several research categories were defined, based on the classes or organisms which the AIBS suggested as most suitable for research related to a particular objective. For example, with respect to

Table 3-2

BEHAVIORAL RESEARCH PROGRAM SUMMARY

Information Needs	Research Category	Experiments
Man's Capability to change his environment	Mission activities	Accessibility
		Communication and Recording
		Mass Translation
		Monitoring and Observation
		Orientation, Stability, and Restraint
		Personnel Translation
		Restraint and Gross Force Generation
		Restraint and Fine Force Generation
Effects of the environment on man	Basic behavioral integrity	Auditory Function
		Chemical Sense Function
		Higher Mental Function
		Orientation Senses
		Psychomotor Function
		Somesthetic Function
		Visual Function
Effects of man - hardware - environment interactions	Habitability	Clothing
		Food Management
		Hygiene System
		Interior Design
		Interpersonal Factors
		Intrapersonal Factors
		Work-rest-sleep Cycles
		Recreation
		Volume and Layout
		Waste Management
		Water Management

the biorhythm research objective, three research categories are defined: vertebrate, invertebrate, and plant. Representative experiments were then found which were responsive to each of the research categories. The total program is summarized in Table 3-3, which shows the number of representative experiments in the applicable research category and the related research objective.

The resulting program provides broad capability for bioscience research by including the necessary equipment and environmental control systems to permit a wide variety of investigations beyond those specifically programmed. In the formulation of this program, it was recognized that exobiology and remote sensing of terrestrial life were additional significant aims of the NASA bioscience program. However, these areas were eliminated as inappropriate to a manned Earth-orbiting laboratory because of the constraints imposed by Earth orbit and because current or projected technology makes them unrealistic goals within the general time-frame of this laboratory program.

Table 3-3
BIOSCIENCE RESEARCH PROGRAM OUTLINE

	Research Categories				
Research Objectives	Vertebrate	Invertebrate	Plant	Microbial	Cellular
Behavior	3	5	-	-	-
Biorhythms	2	2	2	-	-
Genetics	1	2	-	3	-
Geosensitivity	1	1	2	-	1
Hemodynamics	1	-	-	-	-
Metabolism	2	3	2	1	-
Morphogenesis	2	4	4	-	-
Parasitism	-	1	-	2	-
Reproduction	2	1	-	-	-

3.1.4 Life Support and Protective System Research Program Summary

Flight research in life support and protective systems (LS/PS) has as its goal the advancement of the technology that will support man in long-duration space flight. As a basis for structuring and analysing this research, the study team established three research objectives: (1) flight qualification and/or verification of integrated life support systems, (2) flight qualification and/or verification of subsystems and components, and (3) research in the basic technology which will lead to system development.

The inclusion of equipment-development programs in a life sciences research program may be considered by some as an unusually liberal interpretation of the word "research." These activities, however, are essential to the accomplishment of the goal and therefore are included in the research program structure. The research and/or development activities associated with systems, subsystems, and components were identified by examining the related functional requirements. The resulting research program is shown in Table 3-4. At least one representative experiment associated with each functional requirement has been described. The analysis of these experiments has provided the details of equipment and support requirements which are described in later sections. In many instances, several approaches to a functional requirement are known to be under consideration. Each of these has been identified in Section 4.4.

Table 3-4 (page 1 of 3)

BIOTECHNOLOGY LABORATORY LIFE SUPPORT AND PROTECTIVE SYSTEM INFORMATION NEED

Research Objective	System or Technology	Functional Requirement
Integrated system flight verification and/or qualification	Advanced integrated EC/LS	Life support
	Integrated EC/LS and power systems	Life support and power
	Animal EC/LS	Experiment support
	All EC/LS systems	Maintenance

Table 3-4 (page 2 of 3)

Research Objective	System or Technology	Functional Requirement
Subsystem or component Flight verification and/ or qualification	Atmosphere supply and pressurization	Two-gas control
		Gaging
		Nitrogen and oxygen supply
		Oxygen supply by electrolysis
		Oxygen recovery
	Atmosphere purification and control	Carbon-dioxide control
		Trace contaminant control
		Microbial control and monitoring
	Thermal control	Humidity control
		Process cooling
		Process heating
	Water management	Water recovery
		Potability verification
	Waste management	Feces and urine collection
		Feces processing
	Food management	Food supply
	Crew protection	Clothing--space suit
		Back pack
		Gravity compensation
		Personal hygiene
		Fire protection
		Leakage
		Airlock
Basic technology	Atmosphere supply	Heat transfer
	Atmosphere supply/thermal control/water management	Liquid gas separation

Table 3-4 (page 3 of 3)

Research Objective	System or Technology	Functional Requirement
	Atmosphere supply/thermal control/water management/waste management	Solid and liquid retention
		Solid transport by gas drag
	Thermal control	Atmosphere circulation
		Heat transfer
	Thermal control/water management	Condensation
	Thermal control/water management/waste management/crew protection	Liquid transport by gas drag
	Water management	Liquid and liquid mixing
	Crew protection	Fire prevention
	All life support	Solid and liquid retention
		Solid transport by Crew
		Liquid and solid recovery and retention

3.2 BIOTECHNOLOGY LABORATORY PROGRAM RECOMMENDATIONS

The life sciences research program consists of closely related activities in four research areas: biomedical, behavioral, bioscience, and LS/PS. Each of these areas is concerned with the reactions of living organisms, including man, and with life support for the latter. These activities have little or nothing in common with research activities in other scientific disciplines other than the improvement of man's ability to perform research in those areas as a result of the information gained from life sciences research. Thus, equipment required in a life sciences research laboratory is specialized and, generally, will have little application to research in other disciplines.

Therefore, because of the specialized nature of the research and the facilities required to support it, it is recommended that the biotechnology laboratory portion of a space station program be managed as an integrated project through all its phases. This approach will provide maximum opportunity to ensure that the life sciences research for the missions retains the position of prominence in which it has been placed by recent NASA center studies of space laboratory research programs and configurations. It will further ensure that the physical arrangement of the biotechnology laboratory facility will promote the most efficient application of the equipment which it contains.

The alternate to this integrated project approach is to have the integration of the life sciences research experiments managed as just another part of the total experiment program for the mission(s). Although this approach would no doubt result in a life sciences research facility, the integrated project approach would provide a more effective one for the reasons cited above.

With the integrated-project approach, all aspects of the laboratory program would be managed by a single office. This would include items such as space-station program interfaces, equipment development, laboratory layout and mockups, and laboratory assembly and test. This approach will require an "integrated" management team composed of representatives of at least the three offices (OMSF, OART, and OSSA) concerned with life sciences research. That such a management team will work has been shown by the effectiveness of the NASA team from those three offices which coordinated this study.

The concept of a biotechnology laboratory as a major "slice" of a space station is illustrated in Figure 3-1. A gross schedule of activities associated with the laboratory is also shown. (This study provided the information on experiment equipment indicated under 1968 in the figure.) Details of this schedule are discussed in the following paragraphs.

3.3 ACTIVITIES AND SCHEDULES

The implementation of the biotechnology laboratory as an integrated project within the planned space-station program requires the accomplishment of

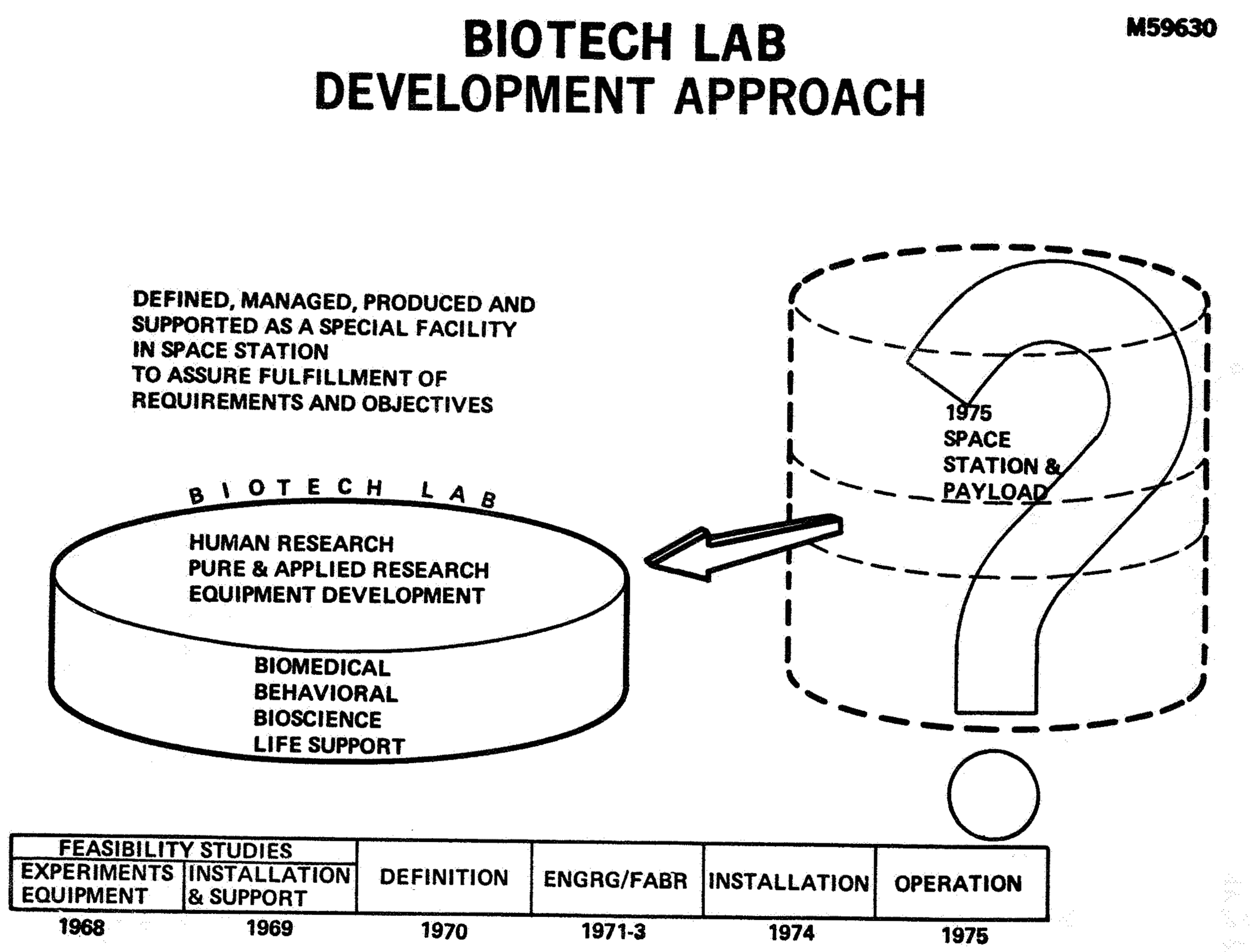

Figure 3-1. Biotech Lab Development Approach

several major tasks. Because of the foresight of several NASA offices associated with the life sciences research to be conducted in such a laboratory, several of the tasks have been accomplished or are in process. The timeliness of these tasks is illustrated in Figure 3-2, which relates the biotechnology laboratory project to the space station programs. The space station program schedule is based on the contractor's understanding of current NASA plans for the Space Station Phase B study and launch date goal.

The space station Phase C effort is the key activity affecting the timing of the biotechnology laboratory project, because the detail design of the space station will begin in this phase. To obtain maximum responsiveness to the biotechnology laboratory requirements in the space station design, these requirements should be imposed in advance, or at least concurrently with the Phase C effort. It is apparent from the schedule that a concurrent approach is practical. The information available in this document, together with information from other programs such as the Integrated Medical Behavioral Laboratory Measurement System (IMBLMS), will permit an indepth study of the requirements of a specific life sciences research program. The results of the study would provide the input to a biotechnology laboratory Phase C effort, beginning in late 1969 at about the same time that the space station Phase C will begin.

Many of the SRT programs for the biotechnology laboratory are already under way and will continue in support of all future missions. A suggested schedule for other activities associated with the laboratory and their relation to the space station program are also shown.

The most important single activity associated with this program is the formulation of the specific life sciences research objectives for the next major space research mission. These objectives must be defined to permit the imposition of specific requirements upon the space station design. Sufficient information is at hand to permit this to be done within the next year.

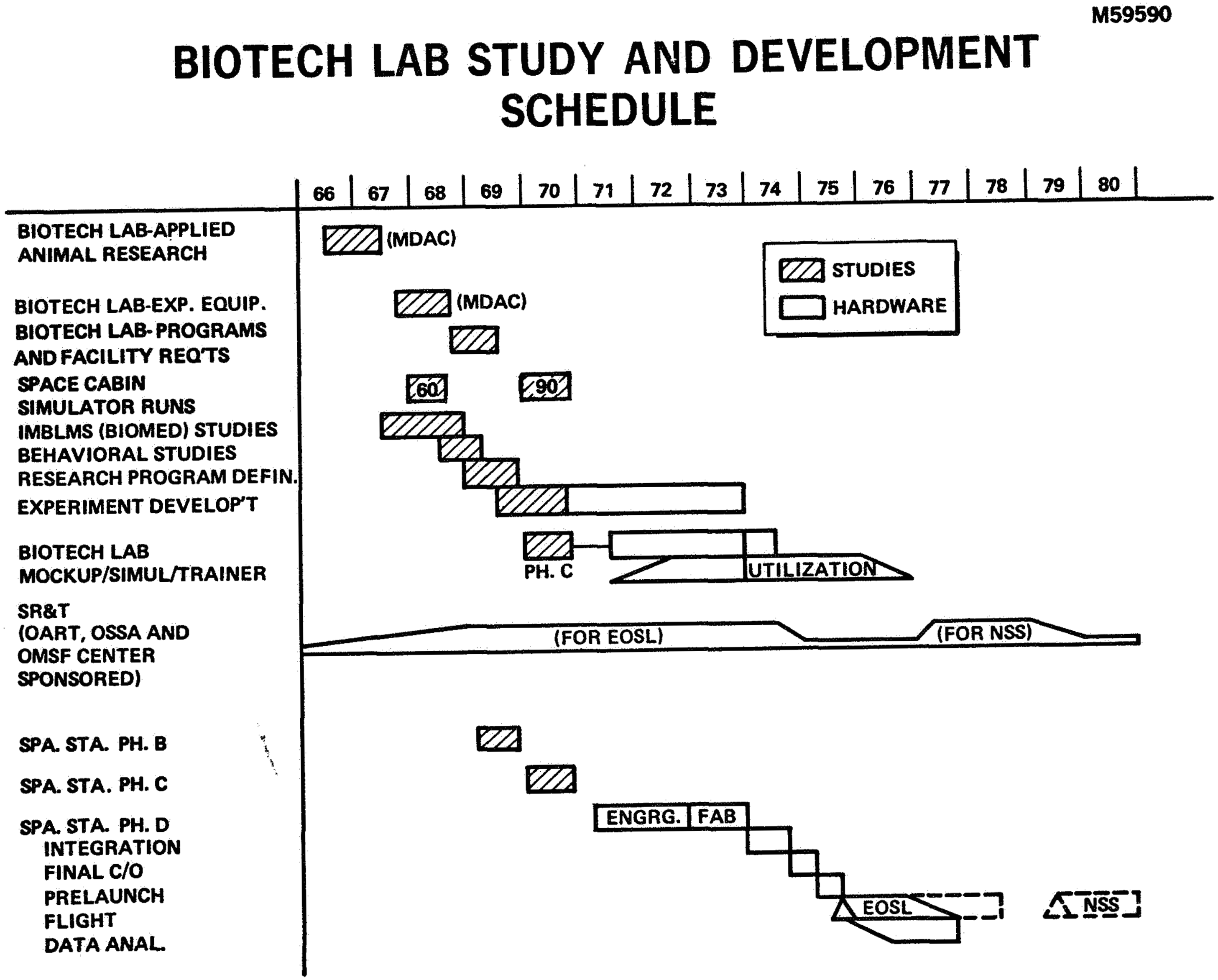

Figure 3-2. Biotech Lab Study and Development Schedule

Section 4
LIFE SCIENCES RESEARCH REQUIREMENTS

This section describes in detail the research programs which were used as a basis for identifying equipment requirements. The Programs are a concensus and thus are a valid base for future space research planning. Measurements and equipment requirements are identified and their common application is presented in matrix charts in Appendix A. The four areas of biomedical and human research, behavioral research, bioscience research, and life support and protective systems research, are covered in separate sections to permit selection of research from each area when "packages" to fulfill specific mission objectives are required.

4.1 BIOMEDICINE AND HUMAN RESEARCH

The program described in this section is directed toward a better understanding of human physiology in long-duration, null-gravity, space flight. This is achieved partly through studies that seek to qualify man for space flight by making measurements on man himself in that environment. However, it is recognized that the long-term qualification of man in space can be achieved only through a program which goes beyond the study of normal space physiology by including research in abnormal physiology, pathogenesis, and therapeutics. The accompanying program of human and animal experiments includes these subjects and transcends any current research plan of this nature.

4.1.1 Research Objectives

The representative biomedical experiments on man and animals in the program described here were selected by responding to the following objectives:

1. Determination of the effects of the space environment on human and other mammalian physiology.

2. Understanding the mechanisms of any alterations to physiology which may occur after prolonged exposure to the space environment, especially weightlessness.
3. Evaluation of preventive or remedial techniques designed to preserve or restore physiologic functions normal to the Earth environment.
4. Prediction of the onset, rate, and degree of physiological alterations which may occur in the weightless environment.
5. Study of induced pathological processes and exploration of the therapeutic means for their correction or elimination.

As these objectives indicate, the program seeks to explore not only normal physiology in the space environment, but also pathophysiological problems that will inevitably occur. Information of this nature clearly cannot be obtained with human subjects except as the natural need to apply therapeutic techniques arises. It seems prudent, therefore, to prepare for this eventuality by making investigations with animals in the experimental areas of pathophysiology and pharmacology before the need to apply the therapies to human subjects arises.

4.1.2 Experiment Selection

In biomedicine-human research there has been a definite evolution of ideas concerning the research objectives identified in Section 4.1.1. This is apparent in a progression of reports by various contractors, scientific evaluation groups, and NASA/government working groups. These and other reports were reviewed to identify specific information needs, which were then grouped under 10 separate subject headings. The divisions which were established to provide a structured approach toward the objectives agreed upon were:

1. Neurological
2. Cardiovascular
3. Pulmonary
4. Gastrointestinal
5. Renal
6. Nutrition and metabolism.
7. Musculoskeletal
8. Endocrine
9. Hematologic
10. Microbiologic and immunologic.

After these specific information needs were established, they were further subdivided into research categories, each of which represents a significant separate but related area of required investigation. Finally, experiment titles taken from all of the basic reference sources, as well as from the other documents, were grouped within the appropriate research categories. This compilation served as the baseline experiment list from which the final program was derived. During the review of individual experiments in the baseline list, it became evident that there was considerable redundancy, even among experiments whose titles differed widely. Such redundancy was eliminated by discarding certain experiments and by consolidating others which overlapped significantly. Comparison of the consolidated list with the information needs previously identified showed that certain critical areas were inadequately covered. In such cases, experiments were designed to produce a complete program. The final group of 55 experiments is directly responsive to all specified information needs and is sufficiently representative of current scientific thought and technology to provide a broad research capability extending considerably beyond the specific program objectives. The final program is shown in Table 4-1.

Table 4-1 (page 1 of 4)
BIOMEDICAL RESEARCH PROGRAM

Information Need	Research Category	Representative Experiments*	
Neurological function	Vestibular function	1-1	Head Movement Effects
		1-2	Otolith and Semicircular Canal Sensitivity
		1-4	Vestibular Electrical Activity**
	Circadian rhythms	1-3	Day-Night Cycle Alterations**
Cardiovascular function	Cardiovascular Deconditioning	1-5	Circulatory Response to Exercise
		1-6	Volume Effects on Arterial Pressure Control System

*Numbers preceding experiment titles correspond to those in Volume II.
**Experiment uses animal subjects.

Table 4-1 (page 2 of 4)

Information Need	Research Category	Representative Experiments*
		1-7 Peripheral Venous Compliance
		1-8 Cardiac Dynamics
		1-9 Intraocular Arterial Blood Pressure
	Deconditioning Countermeasures	1-10 Lower Body Negative Pressure Device Evaluation
		1-11 On-board Centrifuge Evaluation
		1-12 Occlusive Cuffs Evaluation
	Homeostatic mechanisms	1-13 Carotid Sinus Sensitivity
		1-14 Peripheral Arteriolar Reactivity
		1-15 Blood Volume and Distribution
	—	1-16 Carotid Baroreceptor Electrical Activity
	Verification of measurement techniques	1-17 Direct Cardiac Output Measurement**
	Vascular collapse	1-18 Response to Shock Therapy**
Pulmonary function	Ventilatory mechanics	1-19 Pulmonary Mechanics
		1-20 Respiratory Control
	Pulmonary efficiency	1-21 Blood Gas Exchange
		1-22 Lung Cleansing**
	Pulmonary disease	1-23 Induced Pulmonary Infections**
		1-24 Recovery from Non-Infectious Lung Trauma**
Gastrointestinal function	Gastrointestinal function and motility	1-25 Intestinal Absorption
		1-26 Motility and pH

*Numbers preceding experiment titles correspond to those in Volume II.
**Experiment uses animal subjects.

Table 4-1 (page 3 of 4)

Information Need	Research Category	Representative Experiments*
Renal function	Renal physiology	1-27 Indexes of Renal Function
	Renal pathology	1-28 Calculus Formation**
		1-29 Renal Infection**
Nutrition--metabolism	General metabolism	1-30 Energy Metabolism
	Specific metabolites	1-31 Carbohydrate and Fat Metabolism
		1-32 Protein Metabolism
		1-33 Body Fluid Composition
		1-34 Mineral Metabolism
Musculoskeletal function	Skeletal decalcification	1-35 Bone Density
	Work capacity	1-36 Muscle Status
		1-37 Electromyographic Evaluation
	Bone pathology	1-38 Fracture Healing**
		1-39 Induction of Pressure Atrophy**
Endocrine function	Thermal regulation	1-41 Thermal Regulation
	Stress effects	1-40 Endocrine Assays
		1-42 Adrenal and Parathyroid Histopathology and Function**
		1-43 Gonad Histopathological Evaluation**
Hematologic function	Cytogenetics	1-44 Leukocyte Replication
	Cell dynamics	1-45 Erythrocyte Dynamics
		1-46 Leukocyte Dynamics
		1-47 Platelet Dynamics
		1-49 Leukocyte Mobilization after Chemical Challenge
		1-50 Maximum Rate of Erythrocyte Production**

*Numbers preceding experiment titles correspond to those in Volume II.
**Experiment uses animal subjects.

Table 4-1 (page 4 of 4)

Information Need	Research Category	Representative Experiments*
	Coagulation	1-48 Hemostasis
	Tissue pathology	1-51 Wound Healing**
Microbiology and immunology	Microbiology	1-52 Microbial Evaluation of Environment
		1-53 Microbial Evaluation of Crew Members
		1-54 Air Sampling
	Immunology	1-55 Immunological Evaluation of Crew Members

*Numbers preceding experiment titles correspond to those in Volume II.
**Experiment uses animal subjects.

4.1.3 Program Implementation

Because of research and development requirements in certain areas and because of expected facilities constraints, it is not anticipated that the entire biomedical research program will be implemented at one time. The following implementation plan will maximize the efficiency of program development by identifying those areas deserving of the greatest and earliest emphasis.

In developing this plan, all the experiments in this program were evaluated with respect to the urgency of the information needs which they satisfied. It became evident that in all the information need areas there were specific requirements of equal importance. The experiments could not, therefore, be ranked according to strict priority because the information needs for the various functional systems contained equally important information gaps. Thus the total program was divided into three separate phases which might be considered as sequential implementation phases (See Table 4-2). Within each phase, experiments were considered to be equally important. Were the entire laboratory program to be implemented in separate phases, the summary detailed in Table 4-2 would represent an efficient way of answering the most important questions first. Answers to highly desirable but less pressing information needs would be deferred until activation of later program stages.

Table 4-2 (page 1 of 3)

BIOMEDICAL AND HUMAN RESEARCH PROGRAM IMPLEMENTATION PLAN

Information Need	Research Category	Representative Experiments*	
	Phase I Experiments (19)		
Neurological function	Vestibular function	1-1	Head Movement Effects
		1-2	Otolith Semicircular Canal Sensitivity
Cardiovascular function	Cardiovascular deconditioning	1-5	Circulatory Response to Exercise
		1-6	Volume Effects on Arterial Pressure Control System
		1-8	Cardiac Dynamics
	Cardiovascular deconditioning countermeasures	1-10	Lower-Body Negative-Pressure Device
		1-11	On-board Centrifuge Evaluation
		1-12	Occulusive Cuffs Evaluation
	Verification of measurement techniques	1-17	Direct Cardiac Output Measurement**
	Vascular collapse	1-18	Response to Shock-therapy**
Pulmonary function	Ventilatory mechanics	1-19	Pulmonary Mechanics
	Pulmonary disease	1-23	Induced Pulmonary Infections**
Nutrition-metabolism	General metabolism	1-30	Energy Metabolism
	Specific metabolities	1-34	Mineral Metabolism
	Skeletal decalcification	1-35	Bone Density
Musculoskeletal function	Bone pathology	1-38	Fracture Healing**

*Numbers preceding experiment titles correspond to those in Volume II.
**Experiment uses animal subjects.

Table 4-2 (page 2 of 3)

Information Need	Research Category	Representative Experiments*
	Phase I Experiments (19)	
Hematologic function	Cell dynamics	1-50 Maximum Rate of Erythrocyte Production**
	Tissue pathology	1-51 Wound Healing**
Microbiology-immunology	Ecology	1-53 Microbial Evaluation of Crew Members
	Phase II Experiments (16)	
Cardiovascular function	Cardiovascular deconditioning	1-14 Peripheral Arteriolar Reactivity
	Homeostatic mechanisms	1-16 Carotid Baroreceptor Electrical Activity**
Pulmonary function	Pulmonary efficiency	1-21 Blood Gas Exchange
	Pulmonary disease	1-22 Lung Cleansing**
		1-24 Recovery from Non-infectious Lung Trauma**
Renal function	General renal function	1-27 Indexes of Renal Function
Nutrition-metabolism	General metabolism	1-33 Body Fluid Composition
Musculoskeletal function	Work capacity	1-36 Muscle Status
	Bone pathology	1-39 Induction of Pressure Atrophy**
Endocrine function	Stress effects	1-41 Thermal Regulation
		1-43 Gonad Histopathological Evaluation**
Hematologic function	Cell dynamics	1-45 Erythrocyte Dynamics
		1-46 Leukocyte Dynamics
		1-47 Platelet Dynamics
Microbiology-immunology	Microbiology	1-54 Air Sampling
	Immunology	1-55 Immunological Evaluation of Crew Members

*Numbers preceding experiment titles correspond to those in Volume II.
**Experiment uses animal subjects.

Table 4-2 (page 3 of 3)

Information Need	Research Category	Representative Experiments*	
	Phase III Experiments (20)		
Neurological function	Circadian rhythm	1-3	Day Night Cycle Alterations**
	Vestibular function	1-4	Vestibular Electrical Activity**
Cardiovascular function	Cardiovascular deconditioning	1-7	Peripheral Venous Compliance
		1-9	Intraocular Arterial Blood Pressure
	Homeostatic mechanisms	1-13	Carotid Sinus sensitivity
		1-15	Blood Volume and Distribution
Pulmonary function	Ventilatory mechanics	1-20	Respiratory Control
Gastrointestinal function	Gastrointestinal function and efficiency	1-25	Intestinal Absorption
		1-26	Motility and pH
Renal function	Renal pathology	1-28	Calculus Formation**
		1-29	Renal Infection**
Nutrition-metabolism	Specific metabolities	1-31	Carbohydrate and Fat Metabolism
		1-32	Protein Metabolism
Musculoskeletal function	Deconditioning indexes	1-37	Electromyographic Evaluation
Endocrine function	Stress effects	1-40	Endocrine Assays
		1-42	Adrenal and Parathyroid Histopathology and Function**
Hematologic function	Cell dynamics	1-49	Leukocyte Mobilization after Chemical Challenge**
	Cytogenetics	1-44	Leukocyte Replication
	Coagulation system	1-40	Endocrine Assays
Microbiology-immunology	Ecology	1-52	Microbial Evaluation of Environment

*Numbers preceding experiment titles correspond to those in Volume II.
**Experiment uses animal subjects.

Assignment of individual experiments to the various phases was based on information in the references reviewed and on general familiarity with current opinion among participants in organized aerospace medicine research. Certainly, with the passage of time, changes in specific phase assignment would occur either because of technological developments or because answers to certain information needs might become more critical as experience in space increases.

4.1.4 Measurement Requirements

Measurement requirements for this research were developed through two approaches. The information needs and research categories were analyzed for measurements which could be anticipated on the basis of current scientific technology, regardless of the constraints imposed by current technology. Also, individual experiments were analyzed separately to determine the measurements specified in each of the descriptions. The two lists were then consolidated to produce a list which was used to analyze overall program commonalities.

During the review of experiments, it became evident that not all experiments were sufficiently detailed to specify measurements. When such deficiencies were identified, experiment plans which met the stated objectives were originated. The list of required measurements is shown in Table 4-3.

The measurements extracted from analysis or construction of individual experiment descriptions are included in the Experiments Requirements Summaries which are presented in Volume II. The results are also presented in the form of matrix charts (Appendix A) in which individual experiments are compared with the complete list of measurements required for the total biomedical program.

The experiments and measurements embodied in the Integrated Medical and Behavioral Laboratory Measurements System (IMBLMS) concept meet many of the information needs identified in this report. IMBLMS has therefore been a central reference point for this study. It would seem that the final similarities between the IMBLMS program and that outlined in this report, which was derived independently, tend to validate the requirements set forth in both program descriptions.

Table 4-3 (page 1 of 2)

BIOMEDICAL AND HUMAN RESEARCH MEASUREMENTS

General, Environmental

- Airflow
- Ambient air pO_2, pCO_2
- Ambient temperature
- Background radiation
- Cine photography
- Fluid temperature
- Humidity
- Light intensity
- Photography, still (Polaroid, 33 mm, color)
- Photomicrography, still (Polaroid, 33 mm, color)
- Track contaminant levels

Neurological

- Egocentric visual localization of the horizon (EVLH)
- Electroencephalography
- Eye muscle balance
- Nystagmus
- Ocular counter rolling
- Oculogravic illusions
- Oculogyric illusions
- Task performance

Physiological

- Arterial blood pressure
- Arterial filling time
- Ballistocardiography
- Body mass
- Body temperature, core and skin
- Body volume
- Bone density
- Breath-holding time
- Cardiac output
- Circulation time
- Electrocardiography
- Electromyography
- Gastric contraction force
- Gastric volume
- Gastrointestinal motility
- Gastrointestinal pH
- Heart rate
- Muscle size
- Muscle strength
- Phonocardiography
- Plethysmography
- Spirometry
- Venuous filling time

Biochemical--Metabolic

- Blood ACTH
- Blood bicarbonate
- Blood free fatty acids
- Blood glucose
- Blood lactic acid
- Blood PBI
- Blood pH
- Blood pO_2, pCO_2
- Blood TSH
- Blood urea nitrogen
- Serum alkaline phosphatase
- Serum calcium
- Serum chloride
- Serum creatinine
- Serum osmolality
- Serum phosphorus
- Serum potassium
- Serum proteins (total)
- Serum sodium

Table 4-3 (page 2 of 2)

Urine aldosterone	Fecal mass
Urine acidity	Fecal nitrogen
Urine calcium	Fecal calcium
Urine catecholamines	Fecal phosphorus
Urine creatine	
Urine creatinine	
Urine glucose	
Urine nitrogen	
Urine osmolality	
Urine pH	
Urine phosphorus	
Urine steroids	
Urine volume	
Hematological--Microscopic	
Bacterial morphology	Leukocyte count (total and differential)
Bleeding time	Phagocyte index
Cell morphology	Platelet count
Clot retraction	RBC fragility
Clotting time	Reticulocyte count
Cytogenetic evaluation	Sperm count
Erythrocyte count	Sperm motility evaluation
Erythrocyte size	Tissue fixation
Hematocrit	Urinary sediment evaluation
Hemoglobin	
Radioisotopic Tracer Studies	
Blood volume	
Plasma volume	
RBC mass	
RBC survival time	
Specific absorption rates	
Total body water	

4.1.5 Equipment Requirements

The equipment required to perform the biomedical research program is presented here in two forms. Table 4-4 presents a consolidated equipment list derived from the experiment requirements summaries in much the same manner as were the individual measurements. A matrix that relates equipment with experiments may be found in Appendix A. Some of the equipment represented in these tables needs no additional description, while other items required at least some specification, even when no accurate description was possible. These items are further detailed in the equipment description lists

Table 4-4

BIOMEDICINE-HUMAN RESEARCH PROGRAM--EQUIPMENT LIST

Aerosol particle analyzer*
Arterial pressure recorder*
Autoclave*
Automatic cell counter*

Bacterial culture equipment
Ballistocardiograph*
Bone densitometer*

Camera, cine
Camera, still (Polaroid)
Camera, still (35 mm)
Cardiotachometer*
Carotid cuff
Centrifuge, clinical*
Centrifuge, human, short-radius
Chemical analyzers*

Electrocardiograph*
Electroencephalograph*
Electromyograph*
Electrooculograph*
Endoradiosonde*
Erogmeter*

Filtration apparatus
Frozen storage unit

Gas chromatrograph*
Gas flowmeter
Goggles, plethysmographic*

Hemotocrit tubes, capillary
Hemocytometer
Hemoglobinometer*
Humidity recorder*

Incubator, 37°C

Lower-body negative-pressure device*

Manometer, recording*
Mass-measurement device, large*
Mass-measurement device, small*
Microscope*
Muscle dynamometer*

Nebulizer chamber*
Nitrogen analyzer*
Nystagmographic goggles*

Ophtalmoscope*
Oscilloscope*
Osmometer*
Otoscope*
Oximeter, ear*

pH meter*
Phonocardiograph*
Phoropter*
Plethysmograph, capacitance*
Pressure, cuffs limb*
Pressure transducers

Scintillation counter/scaler*
Slide-staining apparatus
Specific ion electrodes*
Spectrophotometer*
Spirometer*
Stethoscope
Stomach tube and balloon
Surgical instruments
Syringes

Temperature recorder*
Thermistors, skin*
Thermistors, rectal*
Thermistor, tympannic*
Tilting motion chair*
Timers

Vision test targets
Volumeter, whole body

*Details in equipment description section.

in Section 7. In many cases, the equipment described is currently under development by various contractors to NASA. When possible, information was obtained which accurately reflects the current status of the individual items described. In other cases, specifications set forth by NASA in proposal requests were used as description and specification guidelines. In still other cases, where a requirement for the described equipment had not been specified elsewhere, the specifications were approximated in accordance with knowledge of the current technology.

It is anticipated that a major portion of the equipment outlined will be provided by the final result of IMBLMS development because a great deal of similarity exists between the IMBLMS program and the biomedical program outlined in this report. Nevertheless, the potential breadth of the research to be performed in the biotechnology laboratory conceived in this study exceeds that of IMBLMS; thus, a few items of equipment will require development if the program is to be accomplished in its entirety.

4.2 BEHAVIORAL RESEARCH

The behavioral research program defined in this study concerns man and the activities he performs in relation to his environment. The program is responsive to the objectives and information needs stated in numerous NASA and aerospace industry reports. The program was developed in the following steps:

1. Statement of the broad objectives of the behavioral research objectives.
2. Identification of the information-need categories related to the objectives.
3. Selection of the research categories and experiments responsive to the information needs.
4. Development of an implementation program plan.

4.2.1 Research Objectives

The objectives formulated for the behavioral research program are a synthesis of those stated throughout the various reference documents. Since these tend to concentrate on specific areas of research rather than on general objectives, it was necessary to restate them in broader terms. Thus, the following objectives were established to provide a basis for the selection of experiments and the definition of an extensive research program:

1. Determination of man's capability to perform meaningful tasks for long-duration missions.
2. Determination of the system design factors that affect morale over extended periods of time in orbit.
3. Determination of the effects of prolonged exposure to the orbital environment on the normal ranges of sensory, perceptual, and psychomotor functions.

These objectives are directed towards optimizing man's performance and providing information which will help to ensure his safety and well-being throughout the mission. Results will be used to develop design criteria for future spacecraft and to aid in formulating operational task requirements.

4.2.2 Experiment Selection

Experiment selection was accomplished by first compiling a catalog of 534 potentially useful experiments, then evaluating their responsiveness to the specific research categories. The catalog was the result of a review of numerous reference documents and MDAC experiment data. From the catalog, a concise listing of 80 experiments that met the following criteria was made:

1. Those that require human capabilities for accomplishment.
2. Those that investigate human capabilities directly or indirectly.
3. Those that are capable of investigating human performance through minor modification of observations.
4. Those that investigate traditional behavioral areas.

The source documents were then reviewed for information needs. Again, no single-source document or proposed program included all the information needs required. Specific information needs with a common purpose were grouped under three major categories: (1) man's effect on his environment, (2) effects of the environment on man, and (3) effects of man-hardware-environment interation. To provide a structured approach to the final selection of experiments, the three information-need categories were subdivided into research categories denoting the distinct areas of investigation required to fulfill each information-need.

The 80 candidate experiments were analyzed for relevancy to the various research categories. Some were responsive to several research categories, others were directed towards only one or two. Degree of responsiveness varied greatly, so that some categories were complete and others were not. There was not enough detailed information to determine the relative importance of a particular experiment to a specific research category.

To avoid redesigning experiments already documented in the literature, a new approach was adopted which consolidated the common objectives, measurements and techniques of the 80 experiments into 26 individual experiments responsive to each of the research categories. Thus, for each experiment area, all the measurements and techniques which might be employed to investigate the total behavioral gamut which could conceivably be included within that classification were identified. Where details regarding measurements, equipment, or time-constraints did not exist, approximations were made. A summary of the total program is shown in Table 4-5.

Evaluation of extravehicular activities (EVA) is not included as a separate experiment, since it overlaps considerably with evaluation of life support and protective systems (LS/PS). Thus, it seemed unreasonable to restate the requirements for pressure suits, life support systems, consumables, and other resources for the behavioral research program. Further the measurement parameters required for the mission activities and basic behavioral integrity experiments are applicable (with few exceptions) to both intravehicular and extravehicular performance. For EVA evaluation, the major functions are egress/ingress, translation, and work performance. All can be effectively measured during pressure-suit evaluation. In fact, the latter requires task performance in order to place appropriate loads on the hardware systems; such performance may be evaluated as part of the behavioral research program.

4.2.3 Program Implementation

Three approaches could be used to implement a behavioral research program. The first, and most desirable, would be to include all 26 experiments on the initial biotechnology laboratory mission.

Table 4-5

BEHAVIORAL RESEARCH PROGRAM SUMMARY

Information Needs	Research Category	Experiments
Man's capability to change his environment	Mission Activities	2-1 Accessibility
		2-7 Communication and Recording
		2-5 Mass Translation
		2-8 Monitoring and Observation
		2-6 Orientation, Stability, and Restraint
		2-4 Personnel Translation
		2-3 Restraint and Gross Force Generation
		2-2 Restraint and Fine Force Generation
Effects of the environment on man	Basic behavioral integrity	2-11 Auditory Function
		2-14 Chemical Sense Function
		2-9 Higher Mental Function
		2-13 Orientation Senses
		2-15 Psychomotor Function
		2-12 Somesthetic Function
		2-10 Visual Function
Effects of man - hardware - environment interactions	Habitability	2-21 Clothing
		2-16 Food Management
		2-19 Hygiene System
		2-22 Interior Design
		2-24 Intrapersonal Factors
		2-25 Interpersonal Factors
		2-26 Work-rest-sleep Cycles
		2-23 Recreation
		2-20 Volume and Layout
		2-18 Waste Management
		2-17 Water Management

This program would be the most flexible. Any information need or research category could be emphasized at any time. The program would be limited, however, by the availability of hardware and techniques. Crew time or other station resources could also constrain the program.

Another approach would be to package the experiments according to each of the three research categories shown in Table 4-5. Packaging related experiments has the advantage of minimizing hardware and facilities required on board. However, there are two problems. First, the only basis for beginning priorities to the three groups would be judgmental. Second, it would be more desirable to have representative experiments from each of the three categories, because one type of research might substantiate (or contradict) the results of another.

The recommended approach is to establish priority ratings for individual experiments within each research category, based on the frequency with which they appear in the literature. From these ratings, sequential experiment programs can be defined. This approach is based on the premise that a frequently recommended experiment represents an urgent information need and, furthermore, appears to be the consensus of the scientific community.

Three candidate experiment packages based on this approach are shown in Table 4-6. They result from a detailed analysis of the measurements and observations required of 80 representative experiments selected from the literature. Experiments within each research category are listed according to decreasing frequency of appearance in the literature, with the most frequent shown at the top of each major column.

Each experiment package is identified by reading across the three columns. The division lines are admittedly judgmental rather than statistical. This concept is not completely arbitrary, however. The three categories of experiments included in each package tend to augment and complement each other. Furthermore, the three packages tend to proceed from the general to the specific. This is desirable because the program should provide the most significant data in the shortest time. In other words, overall task performance degradation would be expected early in the mission. Should it occur, specific causes could be investigated later in the mission. Finally,

Table 4-6

PROGRAM IMPLEMENTATION SUMMARY

Mission Phases	Research Categories		
	Mission Activities	Habitability	Basic Behavioral Integrity
I	2-5 Mass Translation	2-24 Intrapersonal Function	2-15 Psychomotor Functions
	2-4 Personnel Translation	2-25 Interpersonal Function	2-13 Orientation Senses
	2-3 Restraint and Gross Force Generation	2-20 Volume and Layout	
	2-2 Restraint and Fine Force Generation		
	2-6 Orientation, Stability, and Restraint		
II	2-1 Accessibility	2-16 Food Management	2-9 Higher Mental Functions
	2-8 Monitoring and Observation	2-18 Waste Management	2-10 Visual Function
		2-19 Hygiene System	2-11 Auditory Function
		2-21 Clothing	
III	2-7 Communication and Recording	2-17 Water Management	2-14 Chemical Sense Function
		2-22 Interior Design	2-12 Somesthetic Function
		2-26 Work-rest-sleep Cycles	
		2-23 Recreation	

the program is consistent with the three kinds of information needed, and it is provided by the data collected. The desired results can be classified as follows:

1. Those which provide design requirements for future space vehicles.
2. Those which will permit a realistic assignment of integrated crew tasks for future missions.
3. Those which provide insight and understanding into man's adaptive processes in the orbital environment.

4.2.4 Measurement Requirements

The measurement requirements for each of the consolidated experiments were based initially upon those stated in the literature for the original 80 experiments. Additional measurements were added as necessary to make the consolidated experiments completely responsive. A listing of measurements is provided in Table 4-7.

Several of the measurements are used in most of the experiments. Others are specialized and are used in only one research category. Many of the sensory, perceptual, and neurophysiological measurements can be taken with the subject positioned in front of a test console or performing tasks in a limited area. Auditory detection, critical flicker fusion, reaction time, information processing, problem solving, and judgment, for example, will employ relatively standard psychological tests to compare responses in orbit with those made on the ground. Differences, if any, would be attributable to the effects of orbital stressors. These measurements can be readily performed in a minimum of time.

Other measurements deal with complex behavior, e.g., body position/locomotion and mass translation. These measurements will require larger areas and more complex recording equipment. Metabolic measurements are required in conjunction with task performance evaluations in order to assess the impact of energy costs on spacecraft life support systems.

A third type of measurement is needed to evaluate psychological adjustment to the orbital environment. Included are the use of standardized paper and pen tests and of specially developed questionnaires to assess mood, opinion, and intrapersonal and interpersonal dynamics.

Table 4-7

BEHAVIORAL RESEARCH MEASUREMENTS

Sensory, Perceptual, and Psychomotor	
Attention	Judgment
Auditory detection/discrimination	Light and dark adaptation
Body acceleration	Locomotion
Body position	Manipulation
Brightness detection/discrimination	Memory
Color detection/discrimination	Noise sensitivity
Complex sequence	Problem solving
Critical flicker fusion	Reaction time
Depth perception	Tracking
Dexterity	Veridicality
Eye movement	Vigilance
Force production	Visual acuity
Form discrimination	
Physiological, Neurophysiological, and Metabolic	
Electroencephalography	Accommodations utilization
Energy expenditure	Control and display dynamics
Food consumption	Emotional assessment
Galvanic skin response	Event record
Skin sensitivity	Mass motion/acceleration
Smell sensitivity	Mood assessment
Taste sensitivity	Subjective opinion
Water consumption	Time
Miscellaneous	Voice record

In general, the measurements in this program are required to help explain, understand, and predict behavior. They are similar to those used in ground-based laboratories in that they are primarily concerned with recording responses (or events) which can be analyzed on the ground. The on-orbit subjects serve as their own controls, having performed the same experiments in a 1-g environment prior to and subsequent to the mission. A matrix of measurements versus experiment titles is shown in Appendix A.

4.2.5 Equipment Requirements

Equipment required for the behavioral research program is tabulated in Table 4-8. Items were derived from an analysis of the measurements and observations essential to conducting the 26 consolidated experiments. In some cases, equipment requirements were directly translatable from those stated in the literature. More frequently, however, they were developed specifically for this study.

A correlation of equipment items and experiment titles is shown in Appendix A. Some items are functionally compatible and could be combined to reduce constraints on the laboratory. For example, 16 of the 37 equipment items lend themselves to groupings which result in 5 multiple-item combinations: (1) standard dexterity apparatus, CRT and other displays, display-associated

Table 4-8

BEHAVIORAL RESEARCH EQUIPMENT AND SUPPLIES

Measurement Equipment	Support Equipment and Supplies
Accelerometers and recorders	Attachment devices (for restraints)
Analog recorder	Background grid
Audio recorder	Clothing
Cameras	Dionized sterile water
CFF source	Life support equipment/expendables
Color plates	Log book
CRT and other displays	Microsyringes
Display associated controls	Maneuvering aids
EEG sensors and recorder	Masses
Electro oculograph and recorder	Paper and pen tests
Ergometer	Photographic film and magnetic tapes (audio and video)
GSR sensors and recorders	Questionnaires
Gustatory solutions	Recreational devices/supplies
Light source	Restraints
Metabolic monitor	Storage volume
Noise and vibration source	Tape measure
Olfactory aerosols	Tethers
Orthorater	Writing area and surface
Pure tone source	Writing instruments
Somesthetic stimuli	
Standard dexterity apparatus	
Timer	
Torque force apparatus	
Tuning fork	
Veridicality tester	

controls, and an analog recorder; (2) depth-perception tester, orthorater, light source, CFF source, and veridicality tester; (3) pure tone source and noise and vibration source; (4) metabolic monitor, EMG sensors and recorder, and GSR and EEG sensors and recorder; and (5) torque-force apparatus and ergometer.

An integrated measurement system such as indicated in the IMBLMS Request for Proposal would be extremely valuable in the final definition of equipment and techniques for the laboratory. In another recent NASA-funded study, The Utilization of MOL for Early NASA Objectives, it was concluded that an integrated biomedical/behavioral measurement system would significantly reduce not only weight, power, volume, and data-management requirements, but crew time as well. Two of the integrated-measurement devices recommended in that study were the MDAC-designed Computer-Performance and Reference Evaluator (COMPARE) and Visual/Auditory Tester (VAT). Together these two devices can measure all of the basic sensory, psychomotor, and perceptual functions necessary in this research program.

The performance characteristics of the equipment are summarized in Section 7. None of these data were available in the literature; instead, they were developed from Company experience in the laboratory. Experience in underwater and Keplerian - flight studies was extremely valuable. Weight, power, and volume estimates are gross because much of the equipment has not yet been designed for space use.

4.3 BIOSCIENCE RESEARCH

The ability to explore biological organisms or systems in the unique environment of an Earth-orbiting laboratory makes available an entirely new investigative approach to the biosciences. The importance and versatility of this advanced has challenged the ingenuity of a great many bioscientists and has resulted in the proposal of a wide variety of excellent and interesting experiments. The basic aim of the final bioscience research program is to assemble from these proposed experiments a group so representative of current scientific thought and technology that, ideally, any desired experiment could be performed in the laboratory. The following program represents a practical approach to this goal, with a realistic balance between those experiment designs immediately available and those potentially attainable within the scope of the projected orbiting laboratory program.

4.3.1 Research Objectives

Bioscience, the broadest of scientific disciplines, has a variety of potential goals. Among the stated aims of the NASA Bioscience Program as set forth in the April 1968 Bioscience Working Group report is studying "the effects of the space environment on living organisms . . . ."

This goal was taken as the basic charter for the experiments compiled in this section. Such other aims as the search for extraterrestrial life were considered but were discarded as inappropriate to a manned Earth-orbiting laboratory. Similarly, "reconnaissance and study of terrestrial ecology and development of remote sensing life detection techniques," stated in the AIBS report of December 1967, was felt to be generally inapplicable, largely because of the limitations imposed by the current technology. Finally, "development, test, and refinement of bioregenerative life support systems," also stated in the AIBS report, was excluded from the following program, at least as a primary goal, because of its applied and specialized nature. Thus, the research outlined herein conforms rather closely to the definition of a pure or basic science program.

4.3.2 Experiment Selection

Although both the NASA Bioscience Working Group and the AIBS have stated that research on man is a significant objective of the NASA bioscience program, such experiments were excluded from the following program and were treated separately in the section on biomedicine and human research. It should be pointed out, though, that certain areas of bioscience research, while not pursued in this program for the purpose of qualifying man in space, may well provide information of value in that regard. These experiments have been included to provide the breadth and versatility desired in the fully assembled laboratory.

The process of selecting representative experiments was difficult because of the great number of excellent and appropriate experiments proposed in recent years. Selection was simplified, however, when both the NASA coordinators and the MDAC study team agreed to use the AIBS 1967 final report to NASA as a guideline. This report considered basic bioscience objectives and the most efficient means of attaining them. Since the document so clearly represented the consensus of a large group of prominent scientists, its guidance proved invaluable to the selection process. The broad biological research categories outline in the AIBS report include geosensitivity, morphogenesis, metabolism, behavior, parasitism, genetics, and biosynthesis.

To these have been added reproduction and hemodynamics, both of which are aspects of physiology likely to be affected by weightlessness and/or radiation. Although hemodynamics is extensively investigated by noninvasive methods in the biomedicine and human research program, the scope of the experiment outlined in this section is sufficiently large to warrant its inclusion in the program, thereby ensuring that the necessary equipment will be available for associated biological measurements, should they be desired. Similarly, the tissue-culture/cell-reproduction experiment will not only add to the technological capability of the program but should provide much interesting and significant data on a basic process vital to all biosystems. In the overall program outline presented in Table 4-9, the bioscience section was organized in accordance with the AIBS objectives and with the same format as the other segments of the total laboratory program. One difference, however, is the use of the term "research objectives" rather "information needs," since it was agreed that the former was more representative of the intent of any basic science program.

4.3.3 Program Implementation

In this comprehensive bioscience program, the variety of experimental subjects required presents a special problem of implementation. Because of the diverse life-support requirements, the logistics of providing for all desired test organisms becomes complex. Furthermore, it is unrealistic to assume that the technology for supporting these organisms will be uniformly available at the start of the program.

It is difficult to use priority of research objectives as a basis for separating the program into implementation stages because the very nature of this research precludes the assignment of priority values. Therefore, the

Table 4-9 (page 1 of 3).

BIOSCIENCE RESEARCH PROGRAM

Research Objective	Research Category	Representative Experiments	
Behavior	Vertebrate behavior	3-1	Primate Behavior
		3-2	Mouse Growth and Behavior
		3-3	Teleost Behavior
	Invertebrate behavior	3-4	Daphnia Behavior Patterns
		3-5	Cockroach Behavior Patterns
		3-6	Drosophila Behavior
		3-7	Ant Behavior
		3-8	Dinoflagellate Behavior
Biorhythms	Vertebrate biorhythms	3-9	Primate Biorhythm
		3-10	Mouse Biorhythms
	Invertebrate biorhythms	3-11	Cockroach Biorhythms
		3-12	Drosophila Pupal Eclosion
	Plant biorhythms	3-13	Capsicum Biorhythms
		3-14	Avena Biorhythms
Genetics	Vertebrate genetics	3-15	Genetics of Morphologic Adaptation - Teleost
		3-16	Drosophila Genetics
		3-17	Amoeba Genetics
	Microbial genetics	3-18	E. coli Genetics
		3-19	Lysogeny and Genetic Phenomena
		3-20	Neurospora Genetics

Table 4-9 (page 2 of 3)

Research Objective	Research Category	Representative Experiments
Geosensitivity	Vertebrate geosensitivity	3-21 Body Orientation in Fish
	Invertebrate geosensitivity	3-22 Locomotor Responses in Drosophila
	Plant geosensitivity	3-23 Tropic Responses of Capsicum
		3-24 Root and Shoot Tropism - Avena
	Cell geosensitivity	3-25 Human Cell Sensitivity
Hemodynamics	Primate vascular dynamics	3-26 Circulatory Dynamics of Primates
Metabolism	Vertebrate metabolism	3-27 Primate Metabolic Balances
		3-28 Metabolic Rates in the Mouse
	Invertebrate metabolism	3-29 Toxic Effects in Daphnia
		3-30 Drosophila Enzyme Activity
		3-33 Dinoflagellate Luminescence and Photosynthesis
	Plant metabolism	3-31 Crown Gall Metabolism
		3-32 Seed and Seedling Metabolism - Avena
	Microbial metabolism	3-34 Intermediary Metabolism in Neurospora
Morphogenesis	Vertebrate morphogenesis	3-35 Frog Embryogensis in Weightlessness
		3-36 Teleost Development
	Invertebrate morphogenesis	3-37 Head Shape in Daphnia
		3-38 Sexual and Asexual Development in the Flatworm
		3-39 Life Cycle Completion in Drosophila
		3-43 Amoeba Morphogenesis

Table 4-9 (page 3 of 3)

Research Objective	Research Category	Representative Experiments
Morphogenesis (continued)	Plant morphogenesis	3-40 Crown Gall Growth in Weightlessness
		3-41 Avena Life-cycle Completion
		3-42 Amaranthus Germination Potential
		3-44 Bromeliad Streamer Formation
Parasitism	Microbial parasitism	3-45 Altered Mitolic Division Rates in Crown Gall Development
		3-46 Induced and Spontaneous Mouse Leukemia
	Invertebrate parasitism	3-47 Endamoeba Life Histories
Reproduction	Vertebrate reproduction	3-48 Human Cell Aging in Tissue Culture
	Invertebrate reproduction	3-50 Planarian Regeneration
Radiation	Vertebrate radiation effects	3-49 Radiation Effects in the Primate

approach to program implementation was based on the more practical criterion, frequency of utilization of the test organisms. To arrive at an appropriate weighting for the 18 species used, each was scored for the number of times it was utilized in the program. The distribution of this utilization was then determined by listing the number of high, medium-, and low-priority usages which were represented. From these distributions, it was then possible to rank the individual organisms according to their importance as weighted by both high utilization and high experiment priority. The rating and distribution are shown in Table 4-10. For convenience, the table has been arbitarily broken into three separate parts which could represent three phases of program implementation. The first phase (26 experiments) would be composed of those most important in terms of efficient subject utilization and high experiment priority. The second phase (14 additional experiments) would add six new organisms, four of which were used in high-priority experiments. The third phase (10 additional experiments) would add seven new test organisms, one of which was used for a high-priority experiment, and the rest for medium- or low-priority investigations. The experiments associated with each of the three phases are listed in Table 4-11.

The suggested ranking will ultimately be modified on the basis of availability of both experiment and life support hardware. The list is of value, however, for planning the relative emphasis which should be placed on the individual items which require development to support this program.

4.3.4 Measurement Requirements

The measurements required for this research program have been separately identified, since these demonstrate the versatility of the facility to perform research other than that specifically programmed. To evaluate this versatility, the selected experiments were analyzed for required measurements. As in biomedicine, not all experiments selected had sufficiently detailed protocols to permit direct analysis. In those cases, protocols were developed to achieve the stated experiment objectives, and the individual measurements were then extracted. Results of these individual protocol analyses appear individually in Volume II in the form of experiment requirements summaries.

Table 4-10

BIOSCIENCE RESEARCH PROGRAM IMPLEMENTATION PLAN

Phase	Test Organisms	Research Objectives									Experiment Frequency in AIBS* Priorities		
		Behavior	Biorhythms	Genetics	Geosensitivity	Hemodynamics	Metabolism	Morphogenesis	Parasitism	Reproduction	High*	Medium*	Low*
I	Drosophila	X	X	X	X		X	X			5	0	1
	Primate	X	X			X	X			X	5	0	0
	Avena		X		X		X	X			3	1	0
	Mouse	X	X				X		X		2	2	0
	Crown Gall						X	X	X		3	0	0
	Fish	X		X	X			X			2	0	2
II	Daphnia	X					X	X			1	1	1
	E. coli			X					X		1	1	0
	Neurospora			X			X				1	1	0
	Cockroach	X	X								1	1	0
	Capsicum		X		X						0	2	1
	Planarian							X		X	0	2	0
III	Amoeba			X				X	X		0	1	2
	Frog							X			1	0	0
	Dinoflagellate	X					X				0	1	1
	Ant	X									0	1	0
	Bromeliad							X			0	1	0
	Cell culture									X	0	1	0
	Amaranthus							X			0	0	1

*AIBS Priority Rating; AIBS Report to NASA, NASr-132, December 1967

Table 4-11 (page 1 of 3)

BIOSCIENCE RESEARCH IMPLEMENTATION PLAN

Research Objectives	Research Category	Representative Experiments	
	Phase I Experiments		
Behavior	Vertebrate Behavior	3-1 3-2 3-3	Primate Behavior Mouse Growth and Behavior Teleost Behavior
	Invertebrate Behavior	3-6	Drosophila Behavior
Biorhythms	Vertebrate Biorhythms	3-9 3-10	Primate Biorhythms Mouse Biorhythms
	Invertebrate Biorhythms	3-12	Drosophila Pupal Eclosion
	Plant Biorhythms	3-14	Avena Biorhythms
Genetics	Vertebrate Genetics	3-15	Genetics of Morphologic Adaptation - Teleost
	Invertebrate Genetics	3-16	Drosophila Genetics
Geosensitivity	Vertebrate Geosensitivity	3-21	Body Orientation in Fish
	Invertebrate Geosensitivity	3-22	Locomotor Responses in Drosophila
	Plant Geosensitivity	3-24	Root and Shoot Tropism - Avena
Hemodynamics	Primate vascular Dynamics	3-26	Circulatory Dynamics of Primates
Metabolism	Vertebrate Metabolism	3-27 3-28	Primate Metabolic Balances Metabolic Rates in the mouse
	Invertebrate Metabolism	3-30	Drosophila Enzyme Activity
	Plant Metabolism	3-31 3-32	Crown Gall Metabolism Seed and Seedling Metabolism - Avena
Morphogenesis	Vertebrate Morphogenesis	3-36	Teleost Development
	Invertebrate Morphogenesis	3-39	Life Cycle Completion in Drosophila

Table 4-11 (page 2 of 3)

Research Objectives	Research Category	Representative Experiments
	Plant Morphogenesis	3-40 Crown Gall Growth in Weightlessness 3-41 Avena Life-Cycle Completion
Parasitism	Microbial Parasitism	3-45 Altered Mitotic Division Rates in Crown Gall Development 3-46 Induced and Spontaneous Mouse Leukemia
Reproduction	Vertebrate Reproduction	3-48 Human Cell Aging in Tissue Culture
	Vertebrate Radiation Effects	3-49 Radiation Effects in the Primate
	Phase II Experiments	
Behavior	Invertebrate Behavior	3-4 Daphnia Behavior Patterns 3-5 Cockroach Behavior Patterns
Biorhythms	Invertebrate Biorhythms	3-11 Cockroach Biorhythms
	Plant Biorhythms	3-13 Capsicum Biorhythms
Genetics	Microbial Genetics	3-18 Coli Genetics 3-19 Lysogency and Genetic Phenomena 3-20 Neurospora Genetics
Geosensitivity	Plant Geosensitivity	3-23 Tropic Responses of Capsicum
Morphogenesis	Invertebrate Morphogenesis	3-37 Head Shape in Daphnia 3-38 Sexual and Asexual Development in the Flatworm
Reproduction	Invertebrate Reproduction	3-50 Planerian Regeneration
	Phase III Experiments	
Behavior	Invertebrate Behavior	3-7 Ant Behavior 3-8 Dinoflagellate Behavior
Genetics	Invertebrate Genetics	3-17 Amoeba Genetics

Table 4-11 (page 3 of 3)

Research Objectives	Research Category	Representative Experiments
Geosensitivity	Cell Geosensitivity	3-25 Human Cell Sensitivity
Metabolism	Invertebrate Metabolism	3-33 Dinoflagellate Luminescence and Photosynthesis
Morphogenesis	Vertebrate Morphogenesis	3-35 Frog Embryogenesis in Weightlessness
	Invertebrate	3-43 Amoeba Morphogenesis
	Plant Morphogenesis	3-42 Amaranthus Germination Potential
		3-44 Bromeliad Streamer Formation
Parasitism	Invertebrate Parasitism	3-47 Endamoeba Life Histories

For convenience, a consolidated list of measurements is shown in Table 4-12. This permits the reader to grasp the overall research potential of the total program. They are also presented in matrix form in Appendix A.

In general, measurements required for a comprehensive bioscience laboratory are quite similar to those detailed for biomedicine. Measurement equipment must often be designed specifically for use in the individual biomodules which contain the environmental control and life support units for the subject organisms. There is less commonality of equipment than might be expected, however, either because health considerations for the crew dictate isolation of equipment or because the circumstances of the bioscience experiments. The possibility of animal-borne diseases transmissable to man, especially in the unknown environment of a spacecraft laboratory, suggests that a relatively complete separation of human and animal research facilities is the most prudent and conservative design approach.

Certain equipment items which make measurements on body fluids, exudates, or excretions which clearly can be utilized for all programs. Similarly there are remote measurements such as electrocardiograms, and electroencephalograms which could utilize common equipment, provided separate body sensors were employed, but even in these cases it is expected that

Table 4-12

BIOSCIENCE RESEARCH PROGRAM MEASUREMENTS LIST

General, Environmental

Air particle count
Ambient air pO_2, pCO_2, pN_2
Ambient temperature
Background radiation levels
Body mass
Chemical trace contaminants
Cine photography
Fluid intake (volume)
Food intake (mass volume)
Light intensity
Light microscopy
Photomicrography
Relative humidity
Specimen mass
Still photography
Time lapse photography

Animal physiology

Arterial blood pressure
Blood flow
Body fat
Body temperature
Bone density
Brain temperature
Capillary blood flow
Cardiac output
Electroencephalography
Electromyography
Electrooculography
Ergometry
Expired air pO_2, pCO_2
Galvanic skin response
Heart rate
Intracranial pressure
Lean body mass
Metabolic rate
Radiation dose
Respiratory rate
Skin temperature
Total body water
Venous pressure

Biochemical, Metabolic

Blood bicarbonate
Blood hematocrit
Blood hemoglobin
Blood plasma volume
Blood RBC mass
Blood total nitrogen
Blood urea nitrogen
Blood volume
Plasma albumin
Plasma globulins
Serum calcium
Serum chloride
Serum creatinine
Serum phosphorus
Serum potassium
Serum sodium
Urine acidity
Urine calcium
Urine creatine
Urine creatinine
Urine microscopic examination
Urine osmolality
Urine pH
Urine phosphorus
Urine protein
Urine steroids
Urine sugar
Urine total nitrogen
Urine volume

Animal/Plant Behavior

Behavior performance
Biological rhythms
Body orientation
Development
Gross body activity
Reproductive behavior

Plant Physiology

Embryo/plant development
Germination rate
Luminescence
Photosynthesis rate
Tropisms

General Biological

Chromosome analysis
Growth rate
Metabolism rate
RNA/DNA kinetics

Biochemical, Metabolic

Fecal calcium
Fecal mass
Fecal nitrogen

schedules and crew availability may require a certain redundancy. A more detailed analysis of these commonalities is presented in another section of this report.

4.3.5 Equipment Requirements

Bioscience equipment requirements fall into two broad categories. The first of these is equipment for the housing and care of the biological organisms: "Organism Environmental Control/Life Support Modules." Included in this category are the systems and subsystems required for the modular organism EC/LS housing configurations. The second equipment category encompasses a broad range and variety of analytical instruments, the need for which depends on the degree of sophistication of the measurements and observations to be performed. The need for these analytical instruments will also depend upon the results of engineering tradeoff studies concerning biological sampling rates, in-flight analyses of samples, in-flight storage of samples, and return of samples for terrestrial laboratory analyses. Equipment in the two categories is listed in Table 4-13. Brief descriptions of each item are provided in Section 7.

In the EC/LS equipment category, the 50 plant and animal experiments could be housed in 20 modular housing enclosures ranging from special primate modules through fish aquariums, insect chambers, and cell-culture containers, to plant growth chambers and seed-culture tanks. Not included within the context of experiment housing are such general animal-holding facilities as cages for backup test animals. All this modular equipment requires supporting research and development technology. Some items are now in the prototype and test stage. Most such equipment has been conceived or designed originally as single-flight experiment packages, generally adapted to unmanned, near-Earth orbiting satellites. However, with minor modifications, these equipment modules can be adapted to a manned orbiting biotechnology laboratory, maintaining most of those features which would tend to minimize requirements for constant or overly frequent, direct human participation in support of the experiment. Such minimum-attention features are highly desirable because of the tremendous overall demands expected on the time of each scientist-astronaut.

Table 4-13

BIOSCIENCE RESEARCH
EQUIPMENT LIST

General Equipment

Autoclave
Automatic cell counter
Automatic plate scanner/counter
Automatic physiological gas monitor
Bone densitometer
Camera, cine
Camera, plate film
Camera, roll film
Camera, polaroid
Camera, video
Centrifuge, organism
Centrifuge; refrigerated, high speed
Clinostat
Colorimeter
Dosimeters
Dry sterilizer
Drying oven
Electroanalytical apparatus
Electrophoresis apparatus
Ergometer, primate
Ergometer, rodent
Freezer
Gas bottles
Gas chromatograph
Histology kit
Incubator
Liquid gasses
Lyophilizer
Mass measurement device (macro)
Mass measurement device (micro)
Mass spectrometer
Micromanipulator
Microscope, light, compound
Microscope, electron
Microscope, dissecting
Microtome
Mixer/shaker
Polarographic gas sensors
Recorder, oscillographic
Recorder, potentiometric, linear
Recorder, voice
Refrigerator
Spectrophotometer, IR
Spectrophotometer, UV-Visible
Ultrasonic cleaner
Vacuum desiccator

Organism EC/LS modules

Amoeba culture chamber
Ant growth chambers
Bacteria chemostat
Bacteriophage flight package
Daphnia containers
Drosophila biorhythm module
Fish aquarium
Frog-egg flight package
Insect chamber
Mouse calorimetric module
Mouse reproduction module
Planaria container
Plant growth chambers
Pocket-mouse ECS module
Primate calorimetry module
Primate godesic module
Seed germination tank
Seedling culture tank
Tissue culture module

The various systems planned and under development for the EC/LS housing modules involve at least 50 subsystem equipment items, most of which are clustered or configured into automated packages. Thus, measuring equipment for monitoring animal bioelectrical signals such as ECG, EEG, EOG, EMG, ZPG, GSR, temperatures, and pressures can be condensed into biotelemetry packages. The primate automated hemodynamic subsystem is comprised of several components, including optical densitometers, a refractometer, a mechanical drive pump, and a infusion/withdrawal syringe. A matrix chart (Appendix A) shows the type of subsystem equipment required by each of the organism EC/LS modules. Although the commonality of a type of subsystem is apparent, this does not imply the commonality of a specific subsystem design. Clearly, the nutrient supply and dispenser for a mouse reproduction module will bear no resemblance to the same subsystem for a flatworm container. On the other hand, a temperature-control subsystem will have broad application.

Finally, the general analytical and analytical support equipment consists of approximately 50 items, including several sophisticated spectral-analysis instruments requiring further development for space-flight rating. The equipment associated with each of the experiments is shown in Appendix A. Various combinations and condensations of these instruments, based on certain shared principles and/or components, have been suggested. It may not be feasible to include certain of the suggested instruments for the earlier orbiting laboratory flights. The chief instrument in this questionable category is the electron microscope, which has large voltage requirements. If electron microscopy analyses are not included as a part of early orbital-flight experiment performances, the requirements placed on such equipment items as the microtome and histology kit will be considerably less, because ultrathin tissue sections will not be needed.

Keen visual observations and a laboratory notebook can, of course, replace a large category of equipment items, such as TV, movie, and Polaroid cameras. But the time requirements placed on the astronaut-scientist as observer will increase enormously without such image recorders.

4.4 LIFE SUPPORT AND PROTECTIVE SYSTEMS RESEARCH

The basic goal of this research, both in Earth and manned Earth-orbiting laboratories, is to advance the technology that supports man during long exposures to the space environment. This study has concerned itself with that research which, when performed in the unique environment of an orbiting laboratory, will contribute to reaching this goal. Identification of requirements was accomplished in the same manner as previously discussed. However, whereas research goals, objectives, and categories had been suggested in the literature in the other areas, in life support and protective systems, no similar organized approach was found. The rationale which guides the study team in the preparation of the research program is described in the following paragraphs.

4.4.1 Research Objectives

A plan of required research for life support and protective systems was structured by first identifying the objectives, information needs, and research categories. It became apparent that, because this research was extensively concerned with hardware development, the concept of information needs and research categories did not provide a natural subdivision of research activities. Research was therefore categorized by "systems" and the associated "functional requirements."

From the review of the literature and current research and development programs, three clear objectives were aimed at "advancing the technology of the support of man":

1. Flight qualification and verification of integrated life support systems.
2. Flight qualification and verification of subsystems and components.
3. Research in basic technology to advance Items 1 and 2.

Emphasis was placed on providing closed integrated life support systems for manned space vehicles. The degree of closure was determined by the capabilities of subsystems and components to regenerate such consummables as oxygen and water. The need for this equipment is understood when the logistics problems presented by resupply of consummables on long Earth-orbiting missions is considered. Other important portions of the system were also investigated.

The many functional requirements of the systems which are part of an integrated system may be satisfied in a variety of ways. For example, in a water condenser - separator associated with humidity control, at least eight methods have been reported in the literature as being actively investigated or recommended for research. Whichever approaches are finally considered to be most promising as a result of Earth laboratory research will require further testing in the orbiting laboratory. The need for this type of subsystem and component testing in the operational environment will make up a large portion of the research program in this area.

Extended mission time calls for increased reliability of equipment. This is particularly true of the life support and protective system equipment, since the success of the mission depends on its proper functioning. Increased functional reliability may be achieved through design and proper maintenance. Effectiveness of maintenance may be tested only in space, since only there may the man-machine interface be studied in an operational environment.

Research in basic technology may be conveniently categorized and subdivided by identifying it with the life support and protective systems and functional requirements which it supports. These subdivisions therefore, provided a natural basis for categorizing this research. As in the area of subsystems and components, several basic technology problems are associated with a functional requirement. The majority of research is concerned with physical phenomena, basic to the operation of life support and protective systems, about which little is known or understood in the weightless environment.

Results of structuring the life support and protective systems research requirements are shown in Tables 4-14 through 4-16. The experiments and hardware or test status are discussed in following paragraphs.

4.4.2 Experiment Selection

Once the research required in this area was identified and categorized, the next step was to select representative experiments which could be analyzed for laboratory and support equipment requirements. The ground rule followed was that the experiment needed the space environment to provide

Table 4-14

BIOTECHNOLOGY LABORATORY LIFE SUPPORT INTEGRATED SYSTEM EXPERIMENTS

System	Functional Requirement	Experiment	Hardware Status* 1	2	3	4	5
Advanced integrated EC/LS	Life support	4-1--Advanced Integrated Life Support System I				X	
		4-2--Advanced Integrated Life Support System II		X			
Integrated EC/LS and power systems	Life support and power	4-3--Integration of Radioisotope Power and Environmental Control/Life Support		X			
Animal EC/LS	Life support	4-4--Advanced Integrated Life Support Systems for Animals		X			
All EC/LS systems	Maintenance	4-5--Maintenance and Repair in Zero G		X			

*1. Basic research and development stage.
2. A working prototype subsystem.
3. Prototypes have been integrated and tested in a simulator.
4. Prototypes have been integrated and tested successfully in a manned simulator.
5. Flight-tested in Mercury, Gemini, and/or Apollo.

Table 4-15 (Page 1 of 5)

BIOTECHNOLOGY LABORATORY LIFE SUPPORT SUBSYSTEM OR COMPONENT EXPERIMENTS

System	Functional Requirement	Experiment	Hardware Status* 1	2	3	4	5
Atmosphere supply and pressurization	Two-gas control	4-6 --Advanced Two-gas Atmosphere-Supply and -Control Subsystem				X	
	Gaging	4-7 --Advanced Fluid Management and Gaging Subsystem		X			
	Nitrogen and oxygen supply	4-8 --Atmosphere-Supply Methods and Components					
		1. Subcritical Storage and Supply		X			
		2. Supercritical Storage and Supply					X
		3. Gaseous Storage and Supply					X
		4. Chemical Storage and Supply				X	
		5. Refrigeration/Reliquefaction Subsystem	X				
		4-9 --Advanced Atmosphere Supply Subsystem		X			
	Oxygen supply by electrolysis	4-10--Electrolysis Methods and Components					
		1. G. E. Double-Membrane Electrolysis Unit			X		
		2. Water-Vapor Cell		X			
		3. KOH Liquid Electrolysis Unit			X		
		4. TRW Porous Electrode Unit		X			
		5. Rotating Hydrogen Diffusion Cell		X			
		4-11--Water Electrolysis Subsystem			X		
	Oxygen recovery	4-12--Oxygen-Recovery Methods and Components					
		1. Sabatier				X	
		2. Acetylene Former	X				
		3. Methane Cracker	X				
		4. Hydrogen Stripper	X				
		5. Bosch			X		
		6. Solid Electrolyte	X				
		7. Molten Carbonate	X				

*1. Basic research and development stage.
2. A working prototype subsystem.
3. Prototypes have been integrated and tested in a simulator.
4. Prototypes have been integrated and tested successfully in a manned simulator.
5. Flight-tested in Mercury, Gemini, and/or Apollo.

Table 4-15 (Page 2 of 5)

System	Functional Requirement	Experiment	Hardware Status* 1	2	3	4	5
		4-13--Integrated Oxygen-Recovery Subsystem					
		1. Waste By-Products Not Used by Attitude Control				X	
		2. Waste By-Products Used by Attitude Control	X				
Atmosphere purification and control	Carbon-dioxide control	4-14--Carbon-Dioxide Collection Methods and Components					
		1. LiOH Expendable Subsystem					X
		2. Regenerative Molecular Sieve with Vacuum Desorption				X	
		3. Regenerative Molecular Sieve with O_2 Recovery				X	
		4. Carbonation Cell		X			
		5. Magnesium Oxide	X				
		6. Solid Amine		X			
		7. Electrodialysis	X				
		4-15--Advanced Integrated Atmosphere-Purification and Thermal-Control Subsystem				X	
	Trace-contaminant control	4-16--Integrated Trace-Contaminant Control and -Monitoring Subsystem					
		1. Mass Spectrometer/Gas Chromatograph		X			
		2. Catalytic Burner				X	
		3. Isotope Toxin Burner		X			
		4. Charcoal Absorption, Partidulate Filters, and Chemisorbent Beds				X	
	Microbial control and monitoring	4-17--Biological Control and Monitoring of Life Support Subsystems					
		1. Filters Regenerated by Killing Microbes by Heat				X	
		2. Silver Ion Generator			X		
		3. Ultraviolet Light				X	
		4. Viable Sampling by Membrane Filtration	X				
		5. Optical and Resistance Measurement		X			

*1. Basic research and development stage.
2. A working prototype subsystem.
3. Prototypes have been integrated and tested in a simulator.
4. Prototypes have been integrated and tested successfully in a manned simulator.
5. Flight-tested in Mercury, Gemini, and/or Apollo.

Table 4-15 (Page 3 of 5)

System	Functional Requirement	Experiment	Hardware Status* 1	2	3	4	5
Thermal control	Humidity control	4-18--Water Condenser-Separator Methods and Components					
		1. Condenser with Liquid Gas Separation by Porous Plate			X		
		2. Condenser with Liquid Gas Separation by Wick Heat Exchanger					X
		3. Condenser with Liquid Gas Separation by Mechanical Spin			X		
		4. Condenser with Liquid Gas Separation by Vortex Tube	X				
		5. Condenser with Liquid Gas Separation by Hydrophobic/Hydrophilic				X	
		6. Condenser with Liquid Gas Separation by Liquid Cyclone Contactor	X				
		7. Condenser with Liquid Gas Separation by Membrane		X			
		8. Vapor Electrolysis	X				
	Process cooling	4-19--Advanced Cooling System Methods and Components					
		1. Radiators					X
		2. Water Boiler					X
		3. Vapor Cycle	X				
		4. Absorption Cycle for Zero g	X				
		5. Cryogenic Cooling System		X			
	Process Heating	4-20--Integrated Thermal Control System Utilizing Waste Heat and Electrical Energy		X			
Water management	Potable water and wash water	4-21--Water-Recovery Methods and Components					
		1. Open- and Closed-Loop Air Evaporation System				X	
		2. Vapor Pyrolysis System		X			
		3. Vacuum Distillation Unit		X			
		4. Membrane Diffusion/Permeation		X			
		5. Vapor Compression Unit		X			
		6. Electrodialysis		X			
		7. Multifiltration			X		
		8. Reverse Osmosis	X				
		9. Electrolytic Pre-Treatment	X				

*1. Basic research and development stage.
2. A working prototype subsystem.
3. Prototypes have been integrated and tested in a simulator.
4. Prototypes have been integrated and tested successfully in a manned simulator.
5. Flight-tested in Mercury, Gemini, and/or Apollo.

Table 4-15 (Page 4 of 5)

System	Functional Requirement	Experiment	Hardware Status* 1	2	3	4	5
		4-22--Regenerative Water Management Subsystem				X	
	Potability verification	4-23--"Flight-Type" Potability Monitoring System		X			
Waste management	Feces and urine collection	4-24--Waste-Management Methods and Components					
		1. Sleeve Attachment		X			
		2. Diaphragm Unit			X		
		3. Gas Entrainment and Centrifugation for Urine Collection and Removal			X		
	Feces Processing	4. Vacuum/Thermal Dehydration System				X	
		5. Chemical Treatment System			X		
		6. Incineration Unit		X			
		7. Activated Sludge System		X			
		8. Waste Used for Attitude Control	X				
		9. Zimmerman Wet Oxidation Waste Reduction Process	X				
		4-25--Complete Waste Management Subsystem				X	
Food management	Food supply	4-26--Food Storage, Preparation, and Feeding Methods					
		1. Freeze-dried Food					X
		2. Glycerol	X				
		3. Algae	X				
		4. Hydrogenomonas	X				
Crew protection	Clothing--space suit	4-27--Protective Clothing and Advanced Space Suit Assemblies					
		1. Litton Suit		X			
		2. Ames Suit		X			
		3. Soft Suit					X
		4. Umbilical Lines					X
		5. Advanced Cooled Suit Undergarments		X			
	Back pack	4-28--EVA Suit and Biopack				X	

*1. Basic research and development stage.
2. A working prototype subsystem.
3. Prototypes have been integrated and tested in a simulator.
4. Prototypes have been integrated and tested successfully in a manned simulator.
5. Flight-tested in Mercury, Gemini, and/or Apollo.

Table 4-15 (Page 5 of 5)

System	Functional Requirement	Equipment	Hardware Status* 1	2	3	4	5
	Gravity compensation	4-29--Cardiovascular Conditioning and Maintenance					
		1. Pressure Cuffs		X			
		2. Lower-Body Negative-Pressure Boot		X			
		3. Centrifugation		X			
		4. Oscillation		X			
		5. Advance Exercising System		X			
	Personal hygiene	4-30--Equipment and Procedures for Personal Hygiene					
		1. Shower with Airflow-Directed Droplets		X			
		2. Sponge Cleaner			X		
		3. Mechanical Vacuum Shaver		X			
	Fire protection	4-31--Fire-Prevention and -Sensing in Zero G or Reduced Gravity					
		1. Fire-Detection Systems				X	
		2. Fire Extinguishers				X	
	Leakage	4-32--Leak Detection		X			
	Airlock	4-33--Flexible Airlock		X			
		4-34--Airlock Gas Conservation		X			

*1. Basic research and development stage.
2. A working prototype subsystem.
3. Prototypes have been integrated and tested in a simulator.
4. Prototypes have been integrated and tested successfully in a manned simulator.
5. Flight-tested in Mercury, Gemini, and/or Apollo.

Table 4-16 (Page 1 of 2)

BIOTECHNOLOGY LABORATORY LIFE SUPPORT BASIC TECHNOLOGY EXPERIMENTS

System	Functional Requirement	Experiment	Test Category* 1	Test Category* 2
Atmosphere supply	Heat transfer	4-35--Density Profiles of Liquids at and Near the Critical Region	X	
Atmosphere supply/thermal control/water management	Liquid gas separation	4-36--Capillary Studies		X
		4-37--Kinetics and Dynamics of Gas Bubbles		X
		4-38--Absorption of Gases by Liquids in Zero G		X
		4-39--Gas-Free Liquid Maintenance	X	
		4-40--Static and Motion Tests of Interface Phenomena		X
Atmosphere supply/thermal control/water management/ waste management	Solid and liquid retention	4-41--Vapor Purge of Liquid Systems in Zero G	X	
	Solid transport by gas drag	4-42--Transport of Solids by Gas Drag		X
Thermal control	Atmosphere circulation	4-43--Solid-to-Gas Heat Transfer in Cabin Air Heating		X
		4-44--Gas-to-Solid Heat Transfer in Cabin Air Cooling		X
		4-45--Cabin Air Distribution and Control		X
Thermal control	Heat transfer	4-46--Effectiveness of Thermal Insulation and Surface Coatings	X	
		4-47--Convective Heat Transfer at Zero G		X
		4-48--Measurement of Solar Absorptivity and Thermal Emissivity of Various Materials by Spectrometry	X	
Thermal control/water management	Heat transfer	4-49--Pool Boiling in Long-term Zero G		X
Thermal control/protective system		4-50--Effect of Wall Temperature, Ventilation Rate, Cabin Pressure, Gas Composition, and Crew Clothing on Comfort Level	X	
Thermal control/water management	Condensation	4-51--Condensing Heat Transfer and Condensation Rate in Heat Exchangers		X
Thermal control/water management/waste management/crew protection	Liquid transport by gas drag	4-52--Transport of Liquids by Gas Drag		X

*1. Man-machine interface and/or life support technological problem that requires the space environment to validate design concepts.
2. Basic data required in null gravity to substantiate analytical concepts and short-duration low-gravity ground-test results.

Table 4-16 (Page 2 of 2)

System	Functional Requirement	Experiment*	Test Category** 1	Test Category** 2
Water management	Liquid and liquid mixing	4-53--Water-Recovery System Pretreatment Mixing		X
Crew protection	Fire prevention	4-54--Composition Mixing and Heat Transfer	X	
		4-55--Solids and Fluids Combustion	X	
All life support	Solid and liquid retention	4-56--Retention Techniques for Liquids and Solids During Equipment Servicing, Repair, and Maintenance	X	
	Solid transport by crew	4-57--Manual Transport of Solids	X	
	Liquid and solid recovery and retention	4-58--Spillage Recovery and/or Cleanup	X	

*1. Man-machine interface and/or life support technological problem that requires the space environment to validate design concepts.

2. Basic data required in null gravity to substantiate analytical concepts and short-duration low-gravity ground-test results.

information in basic technology for LS/PS development or to provide flight qualification and/or verification of LS/PS hardware, either as an integrated system or at the subsystem and component level.

Review of current and proposed research resulted in identifying 58 representative experiments. Relatively few specific descriptions were found in the literature. Most of representative experiments described in this study were conceived by the study team to reflect the research experiments previously identified and the suggestions of the many scientists in this field. The representative experiments associated with each objective are shown in Tables 4-14 through 4-16. Brief descriptive information for each experiment is provided in Volume II. The experiment descriptions were prepared only to the level that permitted definition of major measurement and support equipment items. A summary of the total power, weight, volume, crew, and mission requirements is given in Section 5.

The several design approaches to a functional requirement mentioned earlier are recognized in the experiment list. For instance, the single representative experiment associated with trace-contaminant control covers four approaches. The laboratory requirements described for this experiment will permit research using any of those four methods. It is not implied that all four methods be investigated simultaneously, although this would of course provide distinct advantages. The particular method investigated in any specific mission program will depend on the extent to which it has been carried on in Earth laboratories.

A spinoff result of the study of experiment activities for the life support and protective systems research program was the production of information on the development or test status of equipment in each category. Inasmuch as this information will be useful to program planners, it is included in the research program tables. It was found that design concepts and hardware development could be described by five status levels:

1. Basic research and development.
2. Working prototypes
3. Prototypes integrated and tested in a simulator.
4. Prototypes integrated and tested successfully in a manned simulator.
5. Prototype flight-tested in Mercury, Gemini, and/or Apollo.

Much of the hardware now at Levels 1 and 2 may eventually be tested in a manned space-cabin simulator. Thus, new hardware could potentially reach Level 4. If this occurs, many of the experiments which have been described could be designed using the more advanced concepts. Typical life support subsystems that could fall into this category are those different functional methods for water recovery, oxygen recovery, waste management, and electrolysis that are listed as potential candidates in the experiment list. For example, water recovery from urine by vapor pyrolysis, vapor compression, or diffusion still could replace the air evaporation until experiment that currently is the only method that reached Level 4.

4.4.3 Program Implementation

The implementation of the LS/PS research program is directly dependent on the development of each item of LS/PS hardware and support equipment. The information and hardware development need is principally dependent on duration, crew size, and vehicle launch dates of future missions.

Tables 4-17 through 4-19 present a suggested phased research implementation program. The experiments proposed for Phase I are the highest priority experiments that are necessary to flight-verify regenerative LS/PS's that make possible the missions beyond Apollo and involve equipment furthest advanced in development status. For example, Experiments 4-14 and 4-15 can be used to flight-verify a regenerative molecular sieve for CO_2 removal needed to replace an expendable LiOH unit for missions longer than 14 days. Other high-priority LS/PS experiments in Phase I include those that permit the flight-verification or qualification of a toxin burner (Experiment 4-16), a water-recovery system (4-21), an electrolysis unit for O_2 supply (Experiment 4-10), and a commode (Experiment 4-24 and 4-25). These can be qualified for the space laboratory as separate subsystem experiments or as a part of an integrated LS/PS experiment. For example, Experiment 4-1, Advanced Integrated Life Support System - I with Priority 1 can be used to complete research on one or all of the previously mentioned subsystems. Apollo nonregenerative life support would be used as the primary system while the new equipment was being qualified. The basic technology experiments listed will aid in the future development of LS/PS's. The functional LS/PS methods for each process are many, as noted in the experiment list in Volume II.

Table 4-17 (page 1 of 3)

PROPOSED LIFE SUPPORT AND PROTECTIVE SYSTEM RESEARCH IMPLEMENTATION PROGRAM - PHASE I

Research Objective	System or Technology	Experiment*
Integrated system flight verification and/or qualification	Life support	4-1 - Advanced Integrated Life Support System I
	Maintenance	4-5 - Maintenance and Repair in Zero G
Subsystem flight verification and/or qualification**	Two gas control	4-6 - Advanced Two-Gas Atmosphere-Supply and Control Subsystem
	Nitrogen and oxygen supply	4-8 - Atmosphere Supply Methods and Components
	Oxygen supply by electrolysis	4-10 - Electrolysis Methods and Components
	Carbon dioxide control	4-14 - Carbon-Dioxide Collection Methods and Components
		4-15 - Advanced Integrated Atmosphere-Purification and Thermal-Control Subsystem
	Trace Contaminant control	4-16 - Integrated Trace-Contaminant-Control and Monitoring Subsystem
	Humidity control	4-18 - Water Condenser-Separator Methods and Components
	Process cooling	4-19 - Advanced Cooling System Methods and Components
	Potable water and wash water	4-21 - Water-Recovery Methods and Components
		4-22 - Regenerative Water-Management Subsystem
	Feces and urine collection	4-24 - Waste-Management Methods and Components
		4-25 - Complete Waste-Management Subsystem
	Food supply	4-26 - Food Storage, Preparation, and Feeding Methods

Table 4-17 (page 2 of 3)

Research Objective	System or Technology	Experiment*
	Clothing--space suit	4-27 - Protective Clothing and Advanced Space Suit Assembly
	Back pack	4-28 - EVA Suit and Biopack
	Fire protection	4-31 - Fire Prevention and Sensing in a Zero or Reduced Gravity
	Leakage	4-32 - Leak Detection
Basic technology***	Liquid gas separation	4-39 - Gas-Free Liquid Maintenance
	Solid liquid retention	4-41 - Vapor Purge of Liquid Systems in Zero G
	Solid transport by gas drag	4-42 - Transport of Solids by Gas Drag
	Atmosphere circulation	4-43 - Solid-to-Gas Heat Transfer in Cabin Air Heating
		4-44 - Gas-to-Solid Heat Transfer in Cabin Air Cooling
	Atmosphere circulation	4-45 - Cabin Air Distribution and Control
	Heat transfer	4-46 - Effectiveness of Thermal Insulation and Surface Coatings
		4-47 - Convective Heat Transfer at Zero G
		4-48 - Measurement of Solar Absorptivity and Thermal Emissivity of Various Materials by Spectrometry
	Condensation	4-51 - Condensing Heat Transfer and Condensation Rate in Heat Exchangers
	Liquid transport by gas drag	4-52 - Transport of Liquids by Gas Drag

Table 4-17 (page 3 of 3)

Research Objective	System or Technology	Experiment*
	Solid and liquid retention	4-56 - Retention Techniques for Liquids and Solids During Equipment Servicing Repair, and Maintenance
	Solid transport by crew	4-57 - Manual Transport of Solids
	Liquid solid recovery and retention	4-58 - Spillage Recovery and/or Cleanup

*System or subsystem that has reached a hardware status of 4 or 5 and a Priority 1 rating; also basic technology Priotiry 1 experiments.

**Subsystem can be included in an integrated experiment.

***Basic technology experiment can be included with a subsystem or integrated system experiment.

Table 4-18 (page 1 of 2)

PROPOSED LIFE SUPPORT AND PROTECTIVE SYSTEM RESEARCH IMPLEMENTATION PROGRAM --PHASE II

Research Objective	System or Technology	Experiment*
Integrated system flight verification and/or qualification	Life support	4-2 Advanced Integrated Life Support System II
		4-4 Advanced Integrated Life Support Systems for Animals
Subsystem flight verification and/or qualification**	Gaging	4-7 Advanced Fluid Management and Gaging Subsystem
	Nitrogen and oxygen supply	4-8 Atmosphere Supply Methods and Components
		4-9 Advanced Atmosphere Supply Subsystem
	Oxygen supply by electrolysis	4-10 Electrolysis Methods and Components
		4-11 Water Electrolysis Subsystem
	Oxygen recovery	4-12 Oxygen-Recovery Methods and Components
	Carbon-dioxide control	4-14 Carbon-Dioxide Collection Methods and Components
	Trace contaminant control	4-16 Integrated Trace-Contaminant Control and Monitoring Subsystem
	Microbial control and monitoring	4-17 Biological Control and Monitoring of Life Support Subsystems
	Humidity control	4-18 Water Condenser-Separator Methods and Components
	Process cooling	4-19 Advanced Cooling System Methods and Components
	Process heating	4-20 Integrated Thermal Control System Utilizing Waste Heat and Electrical Energy
	Potable water and wash water	4-21 Water-Recovery Methods and Components

Table 4-18 (page 2 of 2)

Research Objective	System or Technology	Experiment*
	Potability verification	4-23 "Flight-Type" Potability Monitoring System
	Feces and urine collection	4-24 Waste-Management Methods and Components
	Clothing-space suit	4-27 Protective Clothing and Advanced Space Suit Assembly
	Gravity compensation	4-29 Cardiovascular Conditioning and Maintenance Method
	Personal hygiene	4-30 Equipment and Procedures for Personal Hygiene
	Airlock	4-33 Flexible Airlock
Basic technology***	Liquid gas separation	4-36 Capillary Studies
		4-37 Kinetics and Dynamics of Gas Bubbles
		4-40 Static and Motion Tests of Interface Phenomena
	Heat transfer	4-49 Pool Boiling in Long-Term Zero G
		4-50 Effect of Wall Temperature, Veltilation Rate, Cabin Pressure, Gas Composition, and Crew Clothing on Comfort Level
	Liquid and liquid mixture	4-53 Water-Recovery System Pretreatment Mixing
	Fire prevention	4-54 Composition Mixing and Heat Transfer
		4-55 Solids and Fluids Combustion

*Any pertinent system or subsystem experiment that is now in a hardware status of 1, 2, or 3 that attains a 4 rating at least 2 years before experiment must be made available; also basic technology Priority 2 experiments.

**Subsystem can be included in an integrated experiment.

***Basic technology experiment can be included with a subsystem or integrated system experiment.

Table 4-19

PROPOSED LIFE SUPPORT AND PROTECTIVE SYSTEM
RESEARCH IMPLEMENTATION PROGRAM -- PHASE III

Research Objective	System or Technology	Experiment*	
Integrated system flight verification and/or qualification	Life support	4-3	Integration of Radioisotope Power and Environmental Control/Life Support
Subsystem flight verification and/or qualification	Oxygen supply by electrolysis	4-10	Electrolysis Methods and Components
	Oxygen recovery	4-12	Oxygen-Recovery Methods and Components
		4-13	Integrated Oxygen-Recovery Subsystem
	Carbon dioxide control	4-14	Carbon-Dioxide Collection Methods and Components
	Microbial control and monitoring	4-17	Biological Control and Monitoring of Life Support Subsystems
	Potable water and wash water	4-21	Water-Recovery Methods and Components
	Feces and urine collection	4-24	Waste-Management Methods and Components
	Food supply	4-26	Food Storagè, Preparation, and Feeding Methods
Basic technology	Heat transfer	4-35	Density Profiles of Liquids at and Near the Critical Region
		4-38	Absorption of Gases by Liquids in Zero G

*Other system or subsystem experiments that are now in a hardware status of 1, 2, or 3 that attain a 4 rating at least 2 years before experiment must be made available. Also, basic technology Priority 2 experiments not listed in Phase I and II.

The Phase II experiments given in Table 4-18 list more advanced LS/PS's that are not as far along in development as those in Phase I. Additionally, Priority 2 basic technology experiments that are needed to support future development are given. Under normal funding conditions, the time required to bring a new LS/PS subsystem from the working prototype stage to the level of having been proven feasible as an integrated unit in a manned space-laboratory simulator would be from 3 to 5 years. Several more years could be needed to provide a flight-qualified unit developed from prototype equipment test data that have been evaluated in the manned simulators.

Experiment 4-1, Advanced Integrated Life Support System - I, must be flight-verified or qualified before Experiment 4-2 can be changed from Priority 2 to Priority 1. Additionally, before an LS/PS experiment can become a reality, it should at least reach hardware status Level 4 before considering building a flight-type, flight-weight system to be used as an experiment. The reasoning, of course, is that the system should have proven itself at least as a prototype on the ground before the cost of building a flight unit and testing it as an experiment on board a spacecraft is expended. Once Experiment 4-1 is qualified, then it can become the biotechnology laboratory baseline system for future tests of more advanced life support system experiments. The experimental systems, when proven, can be used for future spacecraft. Once other LS/PS's have reached Level 4 they could also be developed into flight-type equipment and flown as "piggyback" experiments while the baseline EC/LS is used for primary support until the more advanced system has been qualified. The basic technology experiments given in Volume II may be completed as part of (1) an integrated life support system test, (2) a subsystem test, or (3) as a separate piggyback experiment.

Table 4-19 lists many experiments that require a longer research and development lead time as well as others that could be conducted as a Phase III. Experiments not performed as part of Phases I and II could be added into a Phase III program. The implementation program previously discussed will require reconfiguration and refinement once a firmer LS/PS experimental program has been developed and approved by the scientific and engineering communities.

It is interesting to note the 28 of the 29 subsystems and component-level experiments could be conducted piggyback in a 1-year period with a power level of less than 600 W. The 29th, airlock pumpdown experiment, requires up to 1kW. The total weight of the experiment test specimens is approximately 1,600 lb. Only one crew member at a time is needed to support 26 of the 29 experiments for 16 hours a day of testing. Two crewmen at a time are required for the other three experiments. The testing period for the three experiments would be 4 hours/day for a 5-month period. The only pacing item that is required to complete the above is the experiment and support equipment availability as a function of vehicle availability and launch date. Those LS/PS experiment requirements that would vary with crew size were designed for a one-man crew to obtain the above power and weight values. Only one type of LS/PS at a time was assumed to be used for each functional method. The power levels and weight values for an LS/PS scaled for larger crews will also provide a practical experimental package. The weight, power, and volume values for these larger crews may be approximated by using the information given in Volume II.

4.4.4 Measurement Requirements

Knowledge of the measurement capability of a research facility is an asset in planning research which digresses from that upon which the facility design is based. Changes in anticipated activities may occur for a variety of reasons. A list of the measurements required by the life support and protective systems research described in this document is given in Table 4-20. Two categories of measurements are listed: those which apply directly to the performance of equipment under test and those which are general in nature.

Additional information is provided by the matrix charts in Appendix A, which show the commonality of the measurements. The most important and common measurements include pressure, temperature, power requirement, humidity, dew point, flow rates, time, gas composition, quantities of materials, water potability, leakage, metabolic output, velocity, and several other items. The data presented in the tables indicate the commonality of measurement type that exists for the presented LS/PS experiments as well as many specialized measurement requirements. These measurement requirements are representative of those for the type of LS/PS experiments that could be

Table 4-20

LIFE SUPPORT AND PROTECTIVE SYSTEMS
RESEARCH MEASUREMENTS

Equipment Performance Measurements

Absorbtivity/emissivity	Leakage
Absorption rate	Liquid composition
Boiloff rate	Performance data
CO_2 removal rate	pH and oxygen demand
Condensation rate	Power level
Contaminant level	Pressure
Density	Reflective index
Dew point	Reliability and maintainability data
Diffusion rate	Surface tension
Efficiency or effectiveness	Surface finish
Electrical conductivity	Temperature
Flow rate	Time
Friction/drag	Use or delivery rate
Gas composition	Vacuum requirement
Gas flow distribution	Viscosity
Gas generation rate	Water conductivity
Heat requirement	Water - removal rate
Heat transfer rate/heat balance	Wetting angle
Humidity	

General Measurements

Acceleration	Metabolic rate
Amps	Microbial contaminants
Biomedical monitoring	Mobility
Burning rate	Motion characteristics
Centrifugal force	Motion picture
Chemical analysis of liquids	Orientation
Chemical contaminants	Palatability of food
Comfort criteria	Surface shapes
Damping	Total energy
Debris generation	Urine/blood/biological samples
Diet	Velocity/velocity profile
Food storage and preparation	Volts
Food and water use rate	Waste generation rate
Ignition time	Water generation rate
Ionized radiation	

Table 4-21

LIFE SUPPORT AND PROTECTIVE SYSTEMS RESEARCH EQUIPMENT REQUIREMENTS

Performance Measurements Equipment

Bubble chamber
CO_2 sensor
Dew point meter
Diffusion columns
Flowmeter
Friction measuring device
Gas chromatograph
Humidity sensor
Infrared spectophotometer
Integrated reflectometer
Liquid gaging unit
Mass spectrometer
Metabolic measuring device
Optical density sensor
Optical pyrometer
Oscillograph
Pressure sensor
Reference background grid
Shadowgraph
Temperature sensor
Timer

General Support Equipment

Accumulator/holding tanks
Accelerometer/velocity meter
Animal housing
Biomedical equipment
Biomedical monitoring equipment
Carbon bag
Chemical/microbial laboratory
Comfort simulator
Crew hygiene protection system
Crew special restraints
Cryogenic supply
Debris disposal/container
Dielectrophorese device
Dosimeter
EC/LS back pack
Emergency backup EC/LS
Ergometer
Fire detector
Fire extinguishing agents
Gas compressor
Gas liquid separator
Hand pump
Heating element
Ignition device
Illumination device
Isotope heater
Leak detector
Liquid container/tank
Log book
Microscope
Movie camera
Orientation device
Photo cell
Plastic squeeze container
Plumbing purge unit
Porous plate water separator
Pressure controller
Pretreatment unit
Pumps, fans, and blowers
Pyrex flask
Radiation laboratory
Radioisotope shielding
Refrigerator
Solid/gas separator
Special animal sampling equipment
Special clothing/space suits
Special space radiator
Still camera
Stiring unit
Test container with bladder
Test food/water dispensers
Tether/umbilicals
Tools for maintenance and repair
Transport container
Vacuum cleaner
Watt/volt/amp meter
Work bench
Zero gravity scale

performed in a space laboratory. The most prominent measurements requirements are those needed to evaluate operational performance and reliability, as would be expected.

4.4.5 Equipment Requirements

Only a few of the 71 support equipment items necessary for the measurements required for the 58 LS/PS experiments have been fully developed for space flight application. The list of equipment is given in Table 4-21. Two categories of equipment are shown: performance measurement equipment and general support equipment. Matrixes of representative support equipment for each of the 58 LS/PS experiments that could be performed in a space laboratory are presented in Appendix A. The data presented in the tables indicate support equipment commonality that exists between LS/PS experiments as well as specialized equipment requirements. The equipment accuracies, weight, power, and volume requirements given were estimated using existing commercial technology as a guideline, except where information on flight-type equipment was available. The equipment description summaries indicate that a minimum of flight-type experiment-support equipment exists. This stresses the importance for the future development of flight-type support equipment for approved high-priority experiments.

The support equipment for measuring many of the more simple LS/PS operational performance characteristics appears to be available or under development. These support equipment items include pressure sensors, temperature sensors, CO_2 sensors, flowmeters, and watt meters. However, items such as gas analysis devices, water-potability analysis equipment, leak-detection/location devices, dew pointers, integrating reflectometers, optical density sensors, optical pyrometers, and other similar equipment included in the 71 support equipment items listed in Section 7 are not available and must be developed in conjunction with the experiments they support. It is estimated that 90% of the different types of support equipment required to complete the experiments must be developed. A description and status summary is given in Section 7 for most of the support equipment items required to make measurements.

Section 5
BIOTECHNOLOGY LABORATORY SUPPORT REQUIREMENTS

The biotechnology laboratory portion of a manned Earth-orbiting space station consists of the facilities and areas in the space vehicle in which research in the life sciences is conducted. The extent of those facilities, and thus the scope of the research which may be conducted in a specific space vehicle configuration, will be constrained by the mission objectives and the accommodation capabilities of the vehicle. The general nature of the requirements which the biotechnology laboratory will impose on any mission are discussed in this section.

As a further aid to planning activities, a summary of the requirements of each experiment is provided. Tables 5-1 through 5-4 cover the experiments in biomedicine, behavior, bioscience, and life support and protective systems, respectively. They are based on the equipment listed for each experiment on the Experiment Requirement Summaries which appear in Volume II.

Three points must be remembered when referring to these tables: (1) the power, weight, and volume information is based on estimates because, in many cases, detailed information concerning individual equipment items is not available; (2) the number of crew members involved and the duration of an experiment will depend on the protocol defined by the investigator; and (3) the requirements for each experiment do not take into account the commonalities which will exist in specific mission experiment programs.

The electrical power shown is the total power required by all the equipment associated with the experiment. In reality, it would never be as large as shown and would depend on the experiment protocol. The weight and volume requirements would be reduced by taking advantage of commonalities.

Table 5-1 (Page 1 of 2)

BIOMEDICAL EXPERIMENTS SUPPORT REQUIREMENTS SUMMARY

Experiment Number*	Experiment Title	Power (W)	Weight (lb)	Volume (cu ft)	Crew Involved	Duration (min.)
1-1	*Head Movement Effects*	340	190	265	2	60
1-2	Otolith and Semicircular Sensitivity	70	33	3	2	60
1-3	Day-Night Cycle Alterations	5	80	11	2	30
1-4	Vestibular Electrical Actively	95	110	230	3	30
1-5	Circulatory Response to Exercise	23	26	3	3	35
1-6	Volume Effects on Arterial Pressure Control Systems	50	40	11	3	50
1-7	Peripheral Venous Compliance	25	7	0.25	3	30
1-8	Cardiac Dynamics	12	0.25	--	2	30
1-9	Intraocular Arterial Blood Pressuring	-	0.15	--	2	10
1-10	Lower-Body Negative-Pressure Device Evaluation	35	35	8.5	3	30
1-11	On-Board Centrifuge Evaluation	65	25	1.5	3	20
1-12	Occlusive Cuffs Evaluation	65	25	1.5	3	20
1-13	Sensitivity Carotid Sinus	21	27	1.5	4	20
1-14	Peripheral Arteriolar Reactivity	12	2	0.04	2	15
1-15	Blood Volume and Distribution	110	20	0.7	3	60
1-16	Carotid Baroreceptor Electrical Activity	40	50	5.5	2	20
1-17	Direct Cardiac Output Measurement	82	125	236	2	20
1-18	Response to Shock Therapy	110	140	236	2	--
1-19	Pulmonary Mechanics	7	12	--	2	2
1-20	Respiratory Central	14	17	0.25	3	20
1-21	Blood Gas Exchange	14	17	28	2	60
1-22	Lung Cleansing	5	180	11	1	60
1-23	Induced Pulmonary Infections	14	200	16	1	10
1-24	Recovery from Non-Infectious Lung Trauma	5	200	15	1	60
1-25	Intestinal Absorption	15	25	4.2	1	60
1-26	Motility and pH	25	40	5	3	50
1-27	Indexes of Renal Function	210	60	7	2	120
1-28	Calculus Formation	230	140	17	1	10

*Numbers correspond to those in Volume II.

Table 5-1 (Page 2 of 2)

Experiment Number*	Experiment Title	Power (W)	Weight (lb)	Volume (cu ft)	Crew Involved	Duration (min.)
1-29	Renal Infection	5	195	14	1	30
1-30	Energy Metabolism	2	45	6.5	2	15
1-31	Carbohydrate and Fat Metabolism	37	33	6	2	60
1-32	Protein Metabolism	38	13	2	2	60
1-33	Body Fluid Composition	280	170	14	3	60
1-34	Mineral Metabolism	10	40	7	2	--
1-35	Bone Density	25	45	1	2	30
1-36	Muscle Status	---	39	6	2	40
1-37	Electromyographic Evaluation	10	60	6.8	2	20
1-38	Fracture Healing	15	40	6	2	20
1-39	Induction of Pressure Atrophy	15	40	6	1	120
1-40	Endocrine Assays	220	105	10	2	60
1-41	Thermal Regulation	12	48	7	2	65
1-42	Adrenal and Parathyroid Histopathology and Function	20	40	5.5	1	45
1-43	Gonad Histopathological Evaluation	---	15	4	1	30
1-44	Leukocyte Replication	---	15	4	2	40
1-45	Erythrocytes Dynamics	15	25	4	2	60
1-46	Leukocytes Dynamics	5	26	4	2	30
1-47	Platelet Dynamics	5	26	4	2	30
1-48	Hemostasis	---	15	4	2	30
1-49	Leukocyte Mobilization after Chemical Challenge	5	195	4	1	30
1-50	Maximum Rate of Erethrocyte Production	5	195	4	1	60
1-51	Wound Healing	190	106	234	1	30
1-52	Microbial Evaluation of Environment	35	31	0.75	2	15
1-53	Microbial Evaluation of Crew Members	15	30	0.7	2	40
1-54	Air Sampling	15	30	0.7	2	30
1-55	Immunological Evaluation of Crew Members	10	35	0.7	2	10

*Numbers correspond to those in Volume II.

Table 5-2

BEHAVIOR EXPERIMENTS SUPPORT REQUIREMENTS SUMMARY

BEHAVIOR EXPERIMENTS SUPPORT REQUIREMENTS SUMMARY

Experiment Number*	Experiment Title	Power (W)	Weight (lb)	Volume (cu ft)	Crew Involved	Duration (min.)
2-1	Accessibility	195	21	4	3	45
2-2	Restraint and Fine Force Generation	200	25	5	3	50
2-3	Restraint and Gross Force Generation	245	100	21	3	40
2-4	Personnel Translation	195	20	4	3	50
2-5	Mass Translation	220	19	2.1	3	50
2-6	Orientation, Stability, and Restraint	220	19	2.1	3	60
2-7	Communication and Recording	225	95	7	3	30
2-8	Monitoring and Observation	225	95	7	2	40
2-9	Higher Mental Functions	100	125	8	1	40
2-10	Visual Function	400	65	10	2	60
2-11	Auditory Function	45	15	3.5	1	25
2-12	Somesthetic Function	170	20	9	2	25
2-13	Orientation Senses	165	16	3	2	30
2-14	Chemical Sense Function	---	---	---	---	---
2-15	Psychomotor Function	225	20	3.8	1	60
2-16	Food Management	165	16	3	2	10
2-17	Water Management	165	16	3	2	10
2-18	Waste Management	165	16	3	2	10
2-19	Hygiene System	165	16	3	1	10
2-20	Volume and Layout	165	16	3	1	10
2-21	Clothing	200	20	3.8	1	5
2-22	Interior Design	9	6	2	1	20
2-23	Recreation	155	11	2	2	10
2-24	Intrapersonal Factors	14	11	2.6	1	40
2-25	Intrapersonal Factors	9	6	2	1	40
2-26	Work/Rest/Sleep Cycles	---	---	---	---	---

*Numbers correspond to those in Volume II.

Table 5-3 (page 1 of 3)

BIOSCIENCE EXPERIMENTS SUPPORT REQUIREMENTS SUMMARY

Experiment No. *	Experiment Title	Power (W)	Weight (lb)	Volume (cu ft)	Duration (days)
3-1	Primate Behavior	1,800	575	200	100
3-2	Mouse Growth and Behavior	225	272	15	360
3-3	Teleost Behavior	175	100	4	60
3-4	Daphnia Behavior Patterns	175	85	4	30
3-5	Cockroach Behavior Patterns	170	80	3	30
3-6	Drosphila Behavior	200	110	3.5	14
3-7	Ant Behavior	200	110	4.5	60
3-8	Dinoflagellate Behavior	225	100	4	120
3-9	Primate Biorhythms	1,800	1,000	200	120
3-10	Mouse Biorhythms	30	190	12	90
3-11	Cockroach Biorhythms	235	140	70	90
3-12	Drosphila Pupal Eclusion	30	32	3	3
3-13	Capsicum Biorhythms	315	120	3	90
3-14	Avena Biorhythms	210	275	8	90
3-15	Genetics of Morphologic Adaptation--Teleost	180	100	4	120
3-16	Drosophila Genetics	800	600	160	14
3-17	Amoeba Genetics	280	500	8.5	40
3-18	E. coli Genetics	2,200	625	19	7
3-19	Lysogency and Genetic Phenomena	600	400	9.5	14
3-20	Neurospora Genetics	320	800	5.5	90

*Numbers correspond to those in Appendix A.

Table 5-3 (page 2 of 3)

Experiment No. *	Experiment Title	Power (W)	Weight (lb)	Volume (cu ft)	Duration (days)
3-21	Body Orientation in Fish	205	80	4	14
3-22	Locomotor Responses in Drosophila	200	110	48.5	14
3-23	Tropic Responses of Capsicum	135	390	8	90
3-24	Root and Shoot Tropism--Avena	75	118	3.5	90
3-25	Human Cell Sensitivity	8	18	0.4	14
3-26	Circulatory Dynamics of Primate	1,485	700	23	90
3-27	Primate Metabolic Balances	1,450	700	21	60
3-28	Metabolic Rates in the Mouse	2,500	500	35	60
3-29	Toxic Effects in Daphnia	75	270	5	30
3-30	Drosophila Enzyme Activity	65	50	3.5	14
3-31	Crown Gall Metabolism	100	155	5	90
3-32	Seed and Seedling Metabolism--Avena	210	350	7	90
3-33	Dinoflagellate Luminescence and Photosynthesis	380	300	9	120
3-34	Intermediary Metabolism in Neurospora	1,300	525	16	90
3-35	Frog Embryo Genesis in Weightlessness	15	40	1.6	1
3-36	Teleost Development	195	115	5.5	120
3-37	Head Shape in Daphnia	100	275	4	30
3-38	Sexual and Asexual Development in the Flatworm	105	90	5	90
3-39	Life Cycle Completion in Drosophila	225	140	6	14
3-40	Crown Gall Growth in Weightlessness	150	300	7.5	90

*Numbers correspond to those in Appendix A.

Table 5-3 (page 3 of 3)

Experiment No. *	Experiment Title	Power (W)	Weight (lb)	Volume (cu ft)	Duration (days)
3-41	Avena Life Cycle Completion	150	285	7	90
3-42	Amaranthus Germination Potential	100	250	4.5	360
3-43	Amoeba Morphogenesis	375	400	12	40
3-44	Bromeliad Streamer Formation	50	100	2	90
3-45	Altered Metotic Division Rates in Crown Gall Development	350	525	13	90
3-46	Induced and Spontaneous Mouse Leukemia	3,500	1,000	44	360
3-47	Endamoeba Life Histories	200	100	9	40
3-48	Human Cell Aging in Tissue Culture	300	100	2.5	90
3-49	Radiation Effects in the Primate	1,200	600	260	360
3-50	Planaria Regeneration	165	300	8.5	90

*Numbers correspond to those in Appendix A.

Table 5-4 (Page 1 of 3)

LIFE SUPPORT AND PROTECTIVE SYSTEM EXPERIMENTS SUPPORT REQUIREMENTS SUMMARY

Experiment Number*	Experiment Title	Power (W)	Weight (lb)	Volume (cu ft)	Crew Involved	Duration (days)
4-1	Advanced Integrated Life Support System I	400**	300**	15**	NA	Mission
4-2	Advanced Integrated Life Support System II	400**	300**	15**	NA	Mission
4-3	Integration of Radioisotope Power and EC/LS	---	600**	65**	2	30
4-4	Advanced Integrated Life-Support Systems for Animals	200	430	400	2	180
4-5	Maintenance and Repair in Zero G	100	75	10	As required	As required
4-6	Advanced Two-Gas Atmosphere-Supply and Control Subsystem	5	8	0.1	NA	30
4-7	Advanced Fluid-Management and Gaging Subsystem	15	440(max)	9	2	40 hr/ Specimen
4-8	Atmosphere-Supply Methods and Components	15**	280**	4.5**	2	90
4-9	Advanced Atmosphere-Supply Subsystem	15**	80**	1.5**	1	30
4-10	Electrolysis Methods and Components	300**	25**	1**	1	90
4-11	Water Electrolysis Subsystem	300**	25**	1**	As required	90
4-12	Oxygen-Recovery Methods and Components	50**	5**	0.5**	2	90
4-13	Integrated Oxygen-Recovery Subsystem	325**	30**	1**	2	90
4-14	Carbon-Dioxide Collection Methods and Components	75**	25**	3**	2	90
4-15	Advanced Integrated Atmosphere-Purification and Thermal-Control Subsystem	150	50	6	2	30
4-16	Integrated Trace-Contaminant Control and Monitoring Subsystem	30**	8**	0.5**	1	90
4-17	Biological Control and Monitoring of Life-Support Subsystems	300	5	3	1	As required
4-18	Water Condenser/Separator Methods and Components	15	10	1	2	1
4-19	Advanced Cooling System Methods and Components	30	50	7	2	40 hr/ Specimen
4-20	Integrated Thermal-Control System Utilizing Waste Heat and Electrical Energy	See 4-3	300**	10**	1	30
4-21	Water-Recovery Methods and Components	100**	50**	2**	2	30

*Numbers correspond to those in Volume II.
**Requirements per man.

Table 5-4 (Page 2 of 3)

Experiment Number*	Experiment Title	Power (W)	Weight (lb)	Volume (cu ft)	Crew Involved	Duration (days)
4-22	Regenerative Water-Management Subsystem	100**	50**	2**	As required	Mission
4-23	Flight-Type Potability Monitoring System	35	15	1.5	1	30
4-24	Waste-Management Methods and Components	50	25	4	4	30
4-25	Complete Waste-Management Subsystem	100	50	9	2	30
4-26	Food-Storage, Preparation, and Feeding Methods	100**	60**	5**	As required	30
4-27	Protective Clothing and Advanced Space Suit Assemblies	100	43	4	2	20 hr
4-28	EVA Suit and Biopack	100	43	4	2	20 hr
4-29	Cardiovascular Conditioning and Maintenance	100	100	16	Crew	Mission
4-30	Equipment and Procedures for Personal Hygiene	45	15	30	Crew	40 hr
4-31	Fire-Prevention and Sensing in Zero G or Reduced-Gravity	150	80	7	2	4 hr/ Experiment
4-32	Leak Detection	10	5	0.5	2	7
4-33	Flexible Airlock	150	20	9	2	4 hr
4-34	Airlock Gas Conservation	1,000	100	150	2	14
4-35	Density Profiles of Liquid At and Near the Critical Region	250	99	2.6	1	40 hr
4-36	Capillary Studies	50	100	3	1	30
4-37	Kinetics and Dynamics of Gas Bubbles	0.5	100	6	1	30
4-38	Absorption of Gases by Liquids in Zero G	50	109	7	1	30
4-39	Gas-Free Liquid Maintenance	10	10	7	1	30
4-40	Static and Motion Tests of Interface Phenomena	50	213	12	1	30
4-41	Vapor Purge of Liquid Systems in Zero G	100	100	8	1	4 hr
4-42	Transport of Solids by Gas Drag	100	100	8	1	40 hr
4-43	Solid-to-Gas Heat Transfer in Cabin Air Heating	40	10	0.5	1	40 hr
4-44	Gas-to-Solid Heat Transfer in Cabin Air Cooling	40	10	0.5	1	40 hr
4-45	Cabin Air Distribution and Control	40	20	3	1	30
4-46	Effectiveness of Thermal Insulation and Surface Coatings	35	170	50	2	Mission

*Numbers correspond to those in Volume II.
**Requirements per man.

Table 5-4 (Page 3 of 3)

Table 5-4 (Page 3 of 3)

Experiment Number*	Experiment Title	Power (W)	Weight (lb)	Volume (cu ft)	Crew Involved	Duration (days)
4-47	Convective Heat Transfer at Zero G	15	175	9.5	2	24 hr/ test
4-48	Measurement of Solar Absorptivity and Thermal Emissivity of Various Materials by Spectrometry	10	36	2.25	1	Mission
4-49	Pool Boiling in Long-Term Zero G	10	10	2	1	20 hr
4-50	Effect of Wall Temperature, Ventilation Rate, Cabin Pressure, Gas Composition, and Crew Clothing on Comfort Level	300	300	180	4	Mission
4-51	Condensing Heat Transfer and Condensation Rate in Heat Exchangers	100	15	8	1	80 hr
4-52	Transport of Liquids by Gas Drag	30	15	0.8	1	200 hr
4-53	Water Recovery System Pretreatment Mixing	10	5	0.2	1	30
4-54	Composition Mixing and Heat Transfer	100	100	8	2	4 hr/ Experiment
4-55	Solids and Fluids Combustion	100	100	8	2	4 hr/ Experiment
4-56	Retention Techniques for Liquids and Solids during Equipment Servicing, Repair, and Maintenance	20	15	1	As required	40 hr
4-57	Manual Transport of Solids	10	2	1	1	30
4-58	Spillage Recovery and/or Cleanup	50	5	0.5	1	5 hr

*Numbers correspond to those in Volume II.

The crew involved in the conduct of the experiments is realistic. However, in the bioscience experiments, because crew involvement will depend on the degree of automation provided and on the final experiment protocol, no attempt was made to estimate the requirement.

The "duration" for biomedicine and behavior is the time required on each occasion to make the observations. The experiments are expected to be performed throughout the mission. This time might be shortened as a result of the observations. The duration of the bioscience and life-support system experiments is the length of mission time required to obtain meaningful results.

5.1 LABORATORY EQUIPMENT COMMONALITIES

The description of common requirements for items of equipment was prepared for two reasons: (1) to facilitate the planning of research programs to maximize the utilization of the laboratory facilities (2) to guide research and development planners to the equipment which should receive earliest attention. The matrix charts in Appendix A describe the equipment commonalities within each research area. The commonalities across the four research areas are shown in Table 5-5. In a more detailed analysis of common equipment applications such as will be possible with a defined set of research objectives for a space mission, it will be necessary to consider the measurement ranges required by the various experiments which use a particular type of equipment. Typical of this problem are the spectrophotometers required by the biomedical and the bioscience research programs. Both areas require a unit which makes optical density measurements in the wavelength range of 200 to 700 mμ. However, bioscience has a requirement for a unit which makes measurements in the range of 2.5 to 3.5μ.

One common requirement not shown in the charts is that of animal life support systems for the bioscience and biomedical research programs. Whether or not the same animal subject may be used for more than one experiment will of course depend upon the nature of the research. Their life support systems impose large demands on the space-station resources; therefore, research in both areas should be conducted if an animal facility is to be installed.

Table 5-5

BIOTHECNOLOGY LABORATORY COMMON REQUIREMENTS

Equipment	Research Area			
	Bioscience	Biomedicine	Behavior	LS/PS
Torque-force apparatus		X	X	
Human centrifuge		X	X	
Ergometer		X	X	X
Electroenecephalograph		X	X	X
Electrocardiograph		X	X	
Electromyograph		X	X	
Calorimeter, respiratory		X	X	
Animal housing and support	X	X		X
Voice recorder	X	X	X	
Still camera	X	X	X	X
Motion picture camera	X	X	X	X
Film-processing equipment	X	X	X	X
Slide-straining apparatus	X	X		X
Bacterial culture equipment	X	X		X
Automatic cell counter	X	X		
Frozen storage unit	X	X		
Autoclave	X	X		
Incubator	X	X		X
Dry heat sterilizer	X	X		
Lyophilizer	X	X		
Radioactive tracers	X	X		
Gas chromatograph	X	X		X
Mass spectrometer	X			X
Mass-measurement device (macro)	X	X		X
Mass-measurement device (micro)	X	X		X
IR spectrophotometer	X	X		X
UV-Visible spectrophotometer	X	X		
pH Meter	X	X		X
Fluid-handling equipment	X	X		X
Centrifuge, clinical	X	X		
Radiation dosimeter	X	X		

5.2 ELECTRICAL POWER REQUIREMENTS

The review of the electrical power requirements of the experiment or laboratory equipment has indicated that, in general, nominal power loads not exceeding 0.5 kVA for a single experiment may be expected. Furthermore, this load will only occur if all the measurement equipment associated with an experiment is operated simultaneously. In most cases, equipment operations will be programmed to minimize instantaneous loads. The major exception to this low power demand of intermittently operated equipment is the operation of the human centrifuge. During periods of positive acceleration, this device may be expected to impose a load of approximately 5 kVA. Even this load will be acceptable with appropriate management of the electrical power system.

The operation of life support modules for experiment subjects required by biomedical and bioscience research will impose continuous loads. In the case of primates, these loads are in the order of 2.5 kVA. Loads of this magnitude must be identified and imposed as a requirement upon the design of the electrical power system for a space station.

5.3 DATA MANAGEMENT

If it is assumed that experiments are timelined to permit reasonable schedules and to provide programs for contingency rescheduling, the process of biological measurements cannot be considered a technological problem. Neither does the imposition of such practical constraints as operation with existing space-station equipment and within present range limitations, tend to alter these assertions to any marked degree.

This fortunate condition occurs because of two major factors. First, biological functions occur or change at a slow rate compared to most electrical or mechanical functions, and it is the rate of change or response time of a measurement that is a limiting quantity in determining whether a measurement may be accommodated on a given transmission link. The second factor, in part resulting from the first, is that the amount of data which must be processed and relayed to the ground is not particularly large nor is the arrival of data urgent.

5.3.1 Data Requirements

A review of the experiments and equipment recommended in the present study provided the source data for Table 5-6. It was determined that most parameters, consisting of position, pressure, temperature, rate, and event measurements, fall into the frequency range of less than 2-cps. Although

Table 5-6

DATA HANDLING

Frequency Response (cps)	Range 1 ($0 \geq f > 2$ cps)	Range 2 ($2 \geq f > 100$ cps)	Range 3 ($100 \geq f > 1000$ cps)	Range 4 ($f > 1000$ cps)
Potential number of measurements	200	5 or more	5 or more	3 or more
Preferred modulation technique	PCM/PM or PCM/PM	PCM/FM or PCM/PM or FM/FM	FM/FM or PCM/PM	AM FM PCM
Degree of handling difficulty	1	2	3	4
Source	Component/ subject status	Cardiograms Blood pressure	Cardiograms Radiosonde Myograms	Voice Television Scan conversion

many were placed in this range because of inherent low-response characteristics, a number of the measurements in their raw form had considerably wider bandwidths. However, the nature of the desired outputs were of a form which would allow use of such signal-conditioning and conversion devices as log counters which would reduce bandwidth requirements.

Table 5-7, generated during a previous study, illustrates the case in handling data of this nature. Although test times for all technologies that were run on a random day were comparable, the number of bits resulting from the behavioral science experiments was less by several orders of magnitude than the number deriving from experiments in other technologies.

5.3.2 Data Handling

The analog parameters in Range 1 are currently being sampled at a rate between a theoretically possible 2 to a maximum of 10 samples/cycle before being quantized. The number of bits per sample range from 4 to 10 or greater, depending on the desired accuracy of the measurement involved. The encoded data are then gated by the data-acquisition subsystem programmer, together with words obtained in digital form, to produce a serial bit stream. Rates for this serial data, if compatibility is to be maintained with the Manned Space Flight Network (MSFN), are 1.6 and 51.2 kbits/sec.

These rate limitations account for the "degree of difficulty" figure attached to parameters falling into Range 3. The rating of 3 results not from any real difficulty in processing the data but from the impact on system capability if many such measurements are made. For example, 5 measurements at 1,000 cps, encoded to 8 bits/sec produce a serial rate of 40 kbits/sec absorbing 80 percent of the system capacity. If the number of channels to be handled is such that this percentage cannot be allocated, a new system utilizing subcarrier oscillators for the high-response measurements must be carried.

New PCM equipment, now coming into general use, has overcome these channel and rate limitations by incorporating flexible formatting which, simply stated, permits only those measurements to be acquired that are

Table 5-7

EXPERIMENT DATA SUMMARY--ONE DAY

Technology: Physical science
Running time: 180 min.

Experiment No.	Duration (sec)	Data Type	No. of Channels	Sample/Word Rate	Bits Per Word	Bit Rate	Total Bits
110	10,000	Digital	1	100	10	1,000	1×10^7
303	10,000	Analog	1	10	--	600	6×10^6
359	10,000	Analog	1	10	--	60	6×10^5
360	10,000	Analog	1	10	--	60	6×10^5
452	10,000	Analog	1	10	--	60	6×10^5
2,515	10,000	Analog	3	10	--	180	1.8×10^6

Technology: Behavioral science (COMPARE test battery)
Running time: 120 min.

Experiment No.	Data Type	No. of Words	Bits Per Words	Bit Rate	Total Bits
86	Digital	261	24	Not applicable	6.26×10^3

Technology: Communications and navigation
Running time: 376 min.

Experiment No.	Duration (sec)	Data Type	No. of Channels	Sample Rate	Bits Per Sample	Bit Rate	Total Bits
1030	4.8×10^3	Analog	190	10	8	1.52×10^4	7.3×10^7
	4.8×10^3	Digital	2	--	100	200	9.6×10^5

Total run time = 10 hr
Total bits = 9.4×10^7
Transmission time (at 1×10^6 bits/sec) = 1.5 min.

needed during the experiment in progress. Therefore, although both Ranges 2 and 3 indicate FM (subcarriers) as a potential technique, use of FM will gradually decrease because of these new PCM methods.

Data in Range 4 are those required for obtaining a verbal and visual record of the manner in which each experiment is performed and also may constitute all or part of the experiment information itself. The bandwidth necessary for acceptable voice is normally specified to be from 300 to 3,000 cps in its analog form. Digital voice specifications vary from 4,800 to 9,600 bits/sec for a vocoder. It is also possible to sample at slightly greater than twice the highest voice frequency and employ straight analog-to-digital conversion at 6 bits/sample (as planned on the Manned Orbiting Laboratory) which results in a considerably higher rate. The signal, whatever its form, may then amplitude- or frequency-modulate a carrier or subcarrier. To reduce the amount of data accummulated, space-station recorders should be voice-operated. They should be of the cassette type and provide 60 min. of storage.

Visual data may be in the form of still photographs, movies, or television. If photographic data are retained in their original form and returned at the end of the mission or during the mission with data recovery capsules (indicated as satisfactory by investigators), the question of transmission does not arise. However, should transmission of film frames be required because of some unforeseen circumstance, electronic scanning with use of cathode ray tubes and photodiodes becomes necessary and rates may become exceedingly high. For example, if a resolution requirement of 100 lines/mm, 35 mm^2 film, and an analog-to-digital conversion ratio of 5 bits/sample are assumed, 6.2×10^7 bits are generated. It becomes readily apparent that if very many frames must be sent and the data are not operated upon with use of data-compression algorithms, a somewhat impossible communications problem may develop.

The return of television signals presents a somewhat analogous situation in that the amount of information generated is a function of frame rate and resolution. Typical video bandwidths range from 70 kHz used for telescope pointing, to 500 kHz on Apollo, to 3 MHz for commercial TV, to 10 MHz for high-resolution industrial systems. Obviously, video greater than 500 kHz will present a serious problem on the MSFN.

5.3.3 Existing Data Facilities

As previously indicated, the MSFN unified S-band will accommodate PCM data at a maximum rate of 51.2 kbits/sec. Seven subcarriers normally used for EVA biomedical monitoring with center frequencies of from 4 to 12 kHz spaced 1.4 kHz apart may be calculated to handle signals with response requirements of from 70 to 175 kHz each, depending on the degree of error that can be tolerated. Three additional subcarriers with center frequencies of 65, 95, and 125 kHz provide data bandwidths of 1.95 kHz, 2.85 kHz, and 3.75 kHz, respectively. Finally, there is the 500-kHz bandwidth capability achieved by directly modulating the FM transmitter carrier and the 300-kHz to 2.3-kHz voice channel which modulates the 1.25-MHz voice subcarrier. These facilities, when compared with requirements, appear to be satisfactory.

5.4 ATTITUDE CONTROL REQUIREMENTS

Only in two research areas have research activities been found which will affect the space station attitude control system. Many of the bioscience experiments have indicated the desirability or necessity of gravitational fields in the order of 10^{-4} g, if meaningful data are to be obtained. The operation of a human centrifuge will perturb the stability of a space station, thereby requiring attitude-control compensation. The remainder of the research may be conducted in the normal operational status of the space station stability.

It appears impractical to ensure the low gravitational field requirements of the bioscience experiments on a manned space station. Although the desired low levels may be experienced briefly, many random disturbances will occur. Crew movement alone will produce changes. Operational requirements of the mission for attitude changes and attitude and pointing requirements of other research such as astronomy or Earth resources, will similarly affect the g-levels. In recognition of these facts, two solutions have been proposed if the requirement cannot be relaxed in a manned space station. The first is a bioscience module within the space station which is isolated from the perturbations described above. The second is a separate, independent module operated in conjunction with a space station and visited periodically by the crew. Both of these solutions require large development programs and disturbing forces would still be exerted during crew observations.

Unless compensated for, centrifuge operation can significantly affect the spacecraft attitude hold, rate stabilization, and orientation. The most efficient means of eliminating the centrifuge effects is by use of such momentum storage devices as control moment gyrós (CMG's). CMG's are primary control actuator candidates for intermediate, long-term space station configurations. These actuators have the desirable characteristics of linear control for attitude performance and momentum storage for the cyclic disturbances. To provide control for centrifuge operation, the CMG's provide an angular momentum vector which negates that of the centrifuge. Hence, the CMG size and configuration must include the angular momentum of the centrifuge and that defined for the mission requirements. For high-g centrifuge operation, such as a re-entry profile, the CMG size may become, for practical design, too large. Control for this case would be provided by the reaction jets.

5.5 ENVIRONMENTAL CONTROL REQUIREMENTS

The life sciences research program will not impose special requirements on the space-station environmental control system. The separate life support modules for experiment subjects, while in general requiring special atmospheres, will be closed systems. Isolation of the area in which these facilities are located may be required to prevent contamination of the cabin atmosphere. In this situation, special provisions would be required to supply cabin atmosphere to the area. Similarly, the area in which fluids are handled may require isolation. However, as mentioned above, this isolation is not required by the research, and it is possible that the design of the life support modules and fluid handling facility will remove the need for isolation.

5.6 CREW SKILLS REQUIREMENTS

The contributive role to be played by scientist-crew members who are specialists in the various space-station experiment protocols has been described in several documents. (See Bibliography) The necessary or desirable crew skills associated with the research activities considered in this study reinforces those recommendations.

Results of this study and of others (e. g. , NASA MOL and MORL) indicate that the primary skill classifications required would include the following: physician, microbiologist, biochemist, and physiologist to conduct, analyze, and interpret experiments, and an electromechanical engineer to maintain equipment and to conduct the LS & PS research.

An on-board physician would greatly enhance experiment capability throughout the mission. A major contribution would be to evaluate and interpret data as it is gathered and to recommend changes in experiment content and protocol. Further, he could supervise preliminary biochemical analyses on-board and thereby eliminate samples which do not show significant change. Samples which do indicate change would be stored on-board and analyzed in more detail on the ground. Detailed on-board analyses are not considered feasible for the 1971 time period because neither appropriate procedures nor flight-rated equipment will be completely developed. Furthermore, detailed analysis is costly in terms of crew time and other station resources. For the NASA MOL, approximately 3 hours/man/day were required for a 6-man crew to perform a comprehensive biomedical-behavioral experiment program. This estimate was based upon having a physician available to supervise and evaluate the program.

The primary skills mentioned above are definable at three levels: technician, general scientist, and specialist, with the latter requiring the most training and experience. The technician's role would be primarily to operate and maintain equipment; the general scientist would analyze and interpret data; the specialist would be responsible for evaluating the overall progress of the specified portions of the experiment program, make decisions, and redirect the program as required.

It is suggested that the crewmen for the biotechnology laboratory be selected largely from the current astronaut pool. With the possible exception of the physician, physiologist, and biochemist, it should not be necessary to select astronauts with specific academic backgrounds; instead they could be trained in the procedures of conducting, observing, and serving as subjects. The extent of cross-training required of analytic and diagnostic skills cannot be defined until experiments are detailed and scheduled and crew size is established. It is anticipated that the physician would have the overall responsibility for the experiment program.

SECTION 6
SUPPORTING RESEARCH AND TECHNOLOGY REQUIREMENTS

The need for a large research and development program of laboratory equipment was well known before this study was undertaken. The specific items of equipment which are applicable to life sciences research and which require development have been identified in this study. The Equipment Description Summaries in Section 7, include brief comments concerning the development requirements of each item of equipment. However, to facilitate the evaluation of the SRT program requirements, the items of equipment have been categorized according to their development status. The development status categores are first, currently available equipment requiring little or no adaptation; second, equipment currently under development; and finally, equipment requiring development but for which no development program could be identified. The laboratory equipment requirements of each of the areas of biomedical and human research, behavioral research, bioscience research, and life support and protective systems research, are listed in Tables 6-1 through 6-4. It should be noted that the lists do not include life support modules for animal or other organism experiment subjects or items under test in life support and protective systems research, since the need for these will depend on the experiment programs selected, and they will be a part of the experiment development. This is discussed in a later section.

The breadth of application of equipment items will be an important consideration in the selection of items which are to receive emphasis in the research and development programs. The information concerning the commonality of equipment listed in the tables will be of assistance in the selection process.

Table 6-1

BIOMEDICAL RESEARCH EQUIPMENT

Available Equipment	
Electrocardiograph	Otoscope
Electroencephalograph	Phonocardiograph
Erogmeter	Limb pressure cuffs
Gas flowmeter	Specific ion electrodes
Hemoglobinometer	Temperature recorder
Ophthalmoscope	Therimistor
Under Development	
Aerosol particle analyzer	Tilting motion chair
Ballistocardiograph	Human centrifuge
Arterial pressure recorder	Endoradiosonde
Automatic cell counter	Gas chromatograph
Bone densitometer	Impedance cardiograph
Carotid cuff	Lower-body negative-pressure device
Muscle dynamometer	Large mass measurement
pH meter	Small mass measurement
Plethysmograph	Nystagmographic goggles
Scintillation counter	Oscilloscope
Spectrophotometer	Ear oximeter
Chemical analyzers	
No Development Underway	
Autoclave	Light microscope
Cardiotachometer	Nebulizer chamber
Clinical centrifuge	Nitrogen analyzer
Plethysmographic goggles	Osmometer
Humidity recorder	Phoropter
Manometer recording	Whole body volumeter

Table 6-2

BEHAVIORAL RESEARCH EQUIPMENT

Available Equipment	
Audio tape recorder	Accelerometers and recorders
Movie camera	Color plates
Still camera	Pure tone source
Video camera	
Equipment Under Development	
Metabolic monitor	Analog Recorder
Torque-force apparatus	Critical flicker fusion (CFF) source
Standard dexterity apparatus depth perceptometer	EMG sensors and recorders
CRT and other displays	GSR and EEG sensors and recorder
Display-associated controls	Ergometer
Equipment Not Now in Development	
Veridicality test	Noise and vibration source
Orthorater	

The measurement range of an item of equipment may vary from experiment to experiment. It is important that equipment developed in response to a common requirement cover all the measurement ranges required. In this regard, it is recommended that measurement ranges required by potential future applications of the equipment also be provided for in the development.

It is recognized that there are several methods by which some measurements may be accomplished. This study did not examine the variety of approaches. The equipment shown for a specific measurement was based on current practice within Earth laboratories or on planned space research activities. It is recommended that the variety of techniques and equipments for making a measurement be examined in depth as part of a development program. Some of the factors to be considered are efficacy of the method, degree of difficulty to calibrate and operate in the weightless environment, reliability and maintainability, data output format, and resources demands.

Table 6-3

BIOSCIENCE RESEARCH EQUIPMENT

Available Equipment	
Automatic cell counter	Movie camera
Clinostat	Plate film camera
Dosimeters	Polaroid camera
Electroanalytical apparatus	Radiation shielding
Electrophoresis apparatus	Radiation source
High-speed oscillographic recorder	Roll film camera
Linear potentiometric recorder	Video camera
Miscellaneous	Voice recorder
Equipment Under Development	
Colorimeter	Mass-measurement device (micro)
Gas chromatograph	Organism centrifuge
Mass spectrometer	Polarographic CO_2 and O_2 sensors
Mass-measurement device (macro)	Primate exerciser/ergometer
Equipment Not Now in Development	
Autoclave	Liquid nitrogen Dewar flask
Automatic plate scanning counter	Lyophilizer
Bone densitometer	Micromanipulator
Colorimeter	Microtome
Compound microscope	Mixer/shaker
Dry heat sterilizer	Refrigerated high-speed centrifuge
Drying Oven	Refrigerator
Electroanalytical apparatus	Rodent exerciser/ergometer
Freezer	Stereoscopic dissecting microscope
Histology kit/slide cabinet	Ultrasonic cleaner
Incubator	UV-visible spectrophotometer
IR spectrophotometer	Vacuum desiccator
Isotope tracer equipment	Veterinary medical kit

Table 6-4

LIFE SUPPORT AND PROTECTIVE SUBSYSTEMS RESEARCH EQUIPMENT

Available Equipment

Illumination device	Flow meter
Aerosol particle analyzer	Accelerometer
MSA indicator tubes and hand-pump	Accumulator
Work bench for maintenance and repair	Holding tanks
Tether	Cryogenic supply
Umbilicals	CO_2 sensor
EC/LS back-pack	Emergency backup EC/LS
Special clothing	Test container with bladder
Space suits	Pressure controller
Pressure sensor	Plastic squeeze container
Temperature sensor	Heating element
	Orientation device

Equipment Under Development

Mass-measurement device	Biomedical monitoring equipment
Total aerosol collector	Metabolic measuring device
Water analysis by total organic carbon (TOC)	Leak detector
Dispersive total hydrocarbon analyzer	Radioisotope shielding
Fire detector	Isotope heater
Fire-extinguishing agents	Pretreatment unit
Optical pyrometer	Debris disposal
Ergometer	Vacuum cleaner
	Solid/gas separator

Equipment Not Now in Development

Mass spectrometer (for trace contaminants)	Nondispersive IR spectrophotometer
Calorimeter or Coleman spectrometer (junior model)	Gas compressor
Turbiditimeter	Reflectometer
	Optical density sensor
	Photo cell

Since this study addressed itself to the research and equipment requirements of the biotechnology laboratory in the space station, the subject of supporting ground programs (other than equipment development) was not considered. However, one cannot study the research to be performed in space without realizing that a large program of research on Earth must precede it. The majority of the research in life sciences is aimed at discovering and understanding the effects of weightlessness on the living organism. However, in the space laboratory several environmental factors in addition to the gravitational field will be changed. To a degree, each of these variables, except weightlessness, may be simulated in a laboratory on Earth. Therefore, those experiments which would be affected by these variables should be conducted in a simulator so that a reference frame will be available for interpretation of the results of the experiment conducted in space. This, of course, would not avoid the synergism of weightlessness and the other factors. The problem of establishing ground controls for the space experiments is expected to impose large demands for both time and money in any space research program.

Section 7
LABORATORY EQUIPMENT DESCRIPTION SUMMARIES

This section contains a brief description of the major items of laboratory equipment which has been identified as a requirement for each research program described in Section 4 of this report. The information was obtained from immediately available sources. In instances where this type of information was not available, estimates were made. Tables 7-1 through 7-4 list the laboratory equipment required for each research program.

In several cases, an item of equipment with the same name and function may be described in each of the four sections, but generally its performance characteristics differ. It is recommended that a wide range of performance characteristics be considered when the requirements for equipment of this type are defined in a development program so that the resulting design will be broadly applicable.

Such current programs as the Integrated Medical Behavioral Laboratory Measurement System (IMBLMS) and the Automated Primate Research Laboratory (APRL) have been cited in cases where the equipment being developed in those programs is either directly applicable or applicable with modification. Commerical equipment now in laboratory use on Earth has been referenced to clarify the performance requirements. This type of equipment generally will require major modification to make it suitable for use in a manned Earth-orbiting laboratory.

Table 7-1 (Page 1 of 4)

BIOMEDICAL AND HUMAN RESEARCH PROGRAM LABORATORY EQUIPMENT DESCRIPTION

Name/Function	Performance Characteristics	Available Model	Power (W)	Weight (lb)	Volume (cu ft)	Remarks
1. Aerosol particle analyzer	Count and size airborne particles in size range of 0.3 to 10μ.	NASA-ERC Cambridge for Apollo	Not applicable	0.25	0.25	Available 1968
2. Arterial pressure recorder	Detects pressures in 0-to 250-mm Hg range; 20-mV output to provide digital readout and analog recording.	Spacelabs; Garrett for Gemini	12	0.8	---	Under development for IMBLMS.
3. Autoclave	Provides steam pressure, electrically or isotopically, to provide 120°C (30 psia).	Numerous commercial none directly applicable	1,150	15	0.05	Requires engineering development.
4. Automatic cell counter	Coulter-type; detects particles in 1 to 10-μ size range.	Commerical model not applicable for space	10 to 12	---	---	Under development for IMBLMS
5. Ballistocardiograph	Miniature accelerometer; detects in range of 0.1 to 35 Hz.	Donner - or Kissler-type U.S. Naval Aeromedical Instruction	Not applicable	0.3	0.02	Under development
6. Bone densitometer	Provides isotope source with calibrated aluminum wedges and associated electronics.	Spacelabs; Lockheed	15	25	0.22	Under development for IMBLMS
7. Cardiotachometer	Detects cardiac R wave with amplified signal; digital readout preferred.	Numerous clinical (Sanborn Harvard Instruments)	24	7.0	0.25	Development required
8. Carotid cuff	Moulded negative-pressure cuff for cervical spine; provides 0- to 5- V analog output, representative of -150 to ±150 mm Hg range.	Prototype available	1	2	0.5	Under development for IMBLMS.
α Centrifuge, clinical	Rotates to 2,500 rpm and produces 0- to 20-g range.	Commercial types e.g., Beckman Instruments	100	8.0	0.25	Requires adaptation.
10. Centrifuge, human	Short-radius type; produces 0- to 6-g range acceleration.	Previous development MDC, U. S. Navy	275	155	205	Specific design for final spacecraft configuration.
11. Chemical analyzers	Automated analyzers; makes various chemical determinations. To utilize spectrophotometric techniques; accuracy ±5% maximum possible and desirable.	Technicon and	Not applicable	Not applicable	Not applicable	Some under development for IMBLMS. None directly applicable at present.
12. Electrocardiograph	Frequency response: 0.2 to 100 Hz ±0.25%. Output signal: 5.0 ± 0.2 Vdc; variable gain: 0.5 to 20Ω.	Spacelabs for Gemini	40 mW	0.2	---	Available now.

Table 7-1 (Page 2 of 4)

Name/Function	Performance Characteristics	Available Model	Power (W)	Weight (lb)	Volume (cu ft)	Remarks
13. Electroencephalograph	Response: 0 to 50 Hz. Multiplex pulse-width modulated output. For oscilloscope display or analog tape recording.	Spacelabs/Bio Com	50 mW	0.4	---	Available now.
14. Electromyograph	Condition: 0- to 100-mV input signal for analog output to display and recorder. Performance similar to ECG conditioner.	E and M Instruments	50 mW	0.4	---	Modified Apollo-type signal conditioner under development.
15. Endoradiosonde	Detects and transmits pressure pH and temperature. Short-range telemeter to on-board rf converter/ recorder.	Rockefeller University	Self-contained	---	---	Under development; available date unknown.
16. Ergometer	Provides calibrated load: 25 to 350 W ± 5% with pedal output 50- to 100-rpm range. Hand or foot operation.	USAF-AMD	Self-contained	15	30	Undergoing flight qualification.
17. Gas chromatograph	Analyzes expired air for O_2 and CO_2 content to be expressed as pO_2, pCO_2, 0- to 100-mm Hg ±5%. Digital readout with analog recording.	Melpar for Apollo	2	7.5	0.2	Available by 1969.
18. Gas flowmeter	Measures and indicates flow in 0.04 to 0.3 lb/hr to 0.3 to 3 lb/hr.	Apollo Series 5000	Not applicable	0.9	---	Available now.
19. Goggles, plethysmographic	Sealed hydrostatic pressure unit with hand pump (bulb) pressure source and recorder; 0- to 200-mm Hg range.	Prototype developed and described.	Not applicable	0.5	0.2	Requires development; can be available by 1970.
20. Hemoglobinometer	Estimates Hgb content by light comparater method using color standards and range of 10- to 20-mg ±5%.	Various commercial types available	Not applicable	0.25	0.01	Available now.
21. Humidity recorder	Records H_2O vapor in 1 to 1,000 ppm by volume. Accuracy ±5% at full scale.	Commercial-type only	1 to 2	2	---	Development required.
22. Impedance cardiograph	Used for computation of cardiac output to provide average base impedance, change, and rate of change in range of 10 to 40 ±3%.	Spacelabs; for Apollo	70 mW	0.8	---	Available by 1969.
23. Lower-body negative-pressure device	Collapsible pressure vessel; provides 0- to 60-cm H_2O negative pressure; continuously variable over range; ventilated.	NASA-MSC for AAP Program: USAF-AMD	---	24	8.3	Available by 1970

Table 7-1 (Page 3 of 4)

Name/Function	Performance Characteristics	Available Model	Power (W)	Weight (lb)	Volume (cu ft)	Remarks
24. Manometer recording	Pressure range: 0 to 500 mm Hg ±0.1%; analog output for digital readout and tape recording.	Various models available	0.25	1.0	0.5	Development required.
25. Mass Measurement, large	Measures masses in 1- to 100-kg range with ±5% accuracy.	Lockheed	35	6	1.9	Under development.
26. Mass measurement, small	Measures masses in 0- to 1,000-g range with ±5% accuracy.	USAF-AMRL	---	2.0	0.3	Available by 1969.
27. Microscope, light	Standard clinical light microscope: 10X to 1,000X magnification: photo adapter integral light source.	Various commercial	25	10	1.0	Can be redesigned for light weight.
28. Muscle dynamometer	Measures muscle force in 0- to 300-lb range ±10% accuracy.	Lockheed	10	4	11	Under development for IMBLMS.
29. Nebulizer chamber	Delivers aerosol particles in 0.5- to 10-μ range, up to density of 10^5/cu ft.	De Vilbiss commercial	Vacuum	2.0	1.0	Requires development and adaptation; available.
30. Nitrogen analyzer	Digests urine/fecal slurry and titrate ammonia salts by Kjeldahl method. Automated with readout of 0 to 500 mg ±5% N_2.	None	0.9	3	0.03	Requires full development; no prototype available.
31. Nystagmographic goggles	Monocular; measure two-dimensional visual space orientation. Cine photo-recording with fiber optics; eyeball rotation 0° to 10° ±1; horizon tilt 0° to 90° ±1°.	Prototype: U.S. Naval Aeromedical Institute.	Not applicable	0.6	---	Prototype developed requires adaptive integration.
32. Ophthalmoscope	Standard clinical type; miniature.	Welch-Allyn	Self-contained	0.1	---	Available now.
33. Oscilloscope	Eight-channel display sweep; 2.5 to 100 mm/sec by manual selection.	Various	25	25	1.1	Will require specific design development for final system configuration.
34. Osmometer	Measures osmotic pressure in aqueous systems; 300- to 3,000-mosmol range with 5% accuracy.	Hewlett-Packard 300 series	200	40	2	Development required for light flight-rated unit.
35. Otoscope	Standard clinical type; miniature.	Welch-Allyn	Self-contained	0.1	---	Available now.
36. Oximeter, ear	Measures blood O_2 saturation 50 to 100% range; accuracy ±5%, uses red and IR filtered photocell.	NASA-ARC	2	0.05	---	Under development; availability date unknown.
37. pH meter	Measures hydrogen ion concentration in pH range of 0 to 11, with accuracy of ±0.1% in temperature range of 10° to 50°C.	Beckman; portable, battery-operated	Not applicable	1.5	0.03	Under development for IMBLMS.

Table 7-1 (Page 4 of 4)

Name/Function	Performance Characteristics	Available Model	Power (W)	Weight (lb)	Volume (cu ft)	Remarks
38. Phonocardiograph	Crystal pickup microphone sensitive to 5 to 4,000 Hz. Signal amplifiers to provide oscilloscope display and analog recording.	NASA-MSC for Gemini Spacelabs for Apollo	40 mW	0.5	---	Available now.
39. Phoropter	Test visual activity and eye muscle balance; phorias to be tested in range of 0 to 10 prism diopters at 0.25Δ intervals.	Keystone, B and L, Titmus	25	5.0	0.04	Flight-weight model required; could be available by 1970.
40. Plethysmograph	Capacitance technique; measures limb blood flow in 0- to 5-liter/min. range. 10% accuracy required. Output as analog signal, 0 to 5 V.	None	0.1	0.15	---	Under development for IBLMS.
41. Pressure cuffs, limb	Pneumatic cuffs--hand-bulb-operated; provide 0- to 200-mm Hg sustainable pressure with gage readout.	Tycos	Not applicable	0.25	0.01	Direct application of existing models possible.
42. Scintillation counter	Liquid and well types. Integration desirable to detect specific activity in ranges 10^{-1} to 10^{-4} μc/ml with 0.5% reproducibility.	None	10	10	0.2	Under development for IMBLMS.
43. Specific ion electrodes	Measure concentrations of various inorganic ions--specific ranges variable. Desired accuracy, ±0.1%.	Beckman	Not applicable	0.1	---	Available and under additional development for null-gravity systems.
44. Spectrophotometer	Multipurpose; measures optical density in λ range 200 to 600 mμ or selected bands by filtration. Accuracy, 0.1%.	Beckman	10 to 25	5	1	Under development for IMBLMS.
45. Spirometer	Measures standard lung volumes and flow rates. Can measure mechanically with analog signal output for data recording.	Various commercial manufacturers	7	12	0.27	Requires development; no commercial model directly applicable.
46. Temperature recorder	Signal conditioner for thermistor output to analog recording.	Spacelabs, Inc. for Gemini/Apollo	Not applicable	0.2	---	Available now.
47. Thermistor	Registers body temperature. Range 35 to 40°C with accuracy of 0.1°C.	Yellow Spring Instruments	Not applicable	0.1	---	Available now.
48. Tilting motion chair	Graybiel Miller type for zero-g operation to calibrated linear and rotary acceleration.	USNAMI for AAP program Lockheed modified	40	25	3.0	Prototype available; modification under development for IMBLMS.
49. Volumeter, whole body	Plastic enclosure for measurement of body volume by gas dilution technique. Desired accuracy, ±2%.	Unknown	Not applicable	0.5	0.1	Used with other gas analyses apparatus for actual determination.

Table 7-2 (Page 1 of 4)

BEHAVIOR EXPERIMENT LABORATORY EQUIPMENT DESCRIPTIONS

Name/Function	Performance Characteristics	Available Model	Power (W)	Weight (lb)	Volume (cu ft)	Remarks
1. Audio tape recorder	Records voice over range of 200 to 9,000 Hz, 10 to 110 dB. Mission time automatically put on tape when activated by voice or push-to-talk switch.	Ampex	---	5.0	1.0	Recommend noise-cancelling mike, voice-activated with minimum delay and 2-sec follow-up. If head phones used, provide sidetone from mike to indicate adequate volume.
2. Movie camera	1 to 64 fps; single-frame exposure; range finder; 16 mm or larger; zoom, wide-angle and telephoto lenses, cartridge load; automatic exposure select; pop-up external viewfinder; film remaining indicator.	Bolex	---	3.0	0.2	All controls should be operable in the pressurized pressure garment assembly (PGA); light source must be included.
3. Still camera	35-mm or larger single lens reflex; automatic exposure select; wide-angle, telephoto and close-up lenses; one-hand operation.	Hasselblad	---	1.5	0.2	Include strobe-type flash and variety of film: color, black and white, high contrast, and high speed.
4. Video camera	Data-transmission capability and light source. Should require only one hand for operation. Standard sweep acceptable.	NASA-MSFC	---	2.0	0.15	Must be operable in the PGA.
5. Timer	0 to 24 hr; 0.01-sec accuracy; sweep second hand; time out; portable; capable of hand or electronic pulse control.	MDAC COMPARE	---	1.0	0.02	Should be capable of intermittent use without reset unless desired.
6. Metabolic monitor	Measures respiration rate and volume. Must be of a mask or mouthpiece type and register from 0 to 6.6 liter and 0 to 80 liter min. pO_2 0 to 2.5 psi: CO_2: 0 to 1.5 psi: temperature sensitivity core: 90° to 101°F: and skin: 50° to 115°F. EKG: 300 to 5,000 μV: bandwidth 0.5 to 50 H_z.	Biomedical apparatus (IMBLMS)	---	4.0	1.0	Some sensors can give EKG and heart interval (requires 3 to 4 sensors plus signal conditioners). Data-transmission capability required; if possible wireless from crewman to vehicle.
7. Torque-force apparatus	Hand strength in knob twisting up to 45 in./lb; hand strength in full grip twisting up to 120 in./lb; hand strength in squeeze up to 175 lb; arm strength at various elbow angles up to 180 lb; backstrength; (vertical pull) up to 650 lb; leg strength (vertical pull) up to 1,950 lb.	MDAC COMPARE IMBLMS	10	4.0	1.0	Should not require another subject for score recording. Should provide range adjustment.

Table 7-2 (Page 2 of 4)

Name/Function	Performance Characteristics	Available Model	Power (W)	Weight (lb)	Volume (cu ft)	Remarks
8. Standard dexterity apparatus	Provides capability for determining aiming and manipulation factors separately.	(SRT) MDAC COMPARE	1	0.5	0.01	These tests typically employ many loose items not acceptable in zero gravity; new norms must be developed for a modified task.
9. Ergometer	Must exercise major flexor and extensor muscle groups by repetition rather than through use of unusually large forces. Whole body push and pull appears appropriate with resistance forces adjustable from 25 to 150 lb.	(SRT)	Not applicable	20.0	2.0	Frictional devices often produce particles from abrasion which may "float" and be inadvertently inhaled or ingested. Some form of "pacer" may be used to time and count repetitions. Heart rate display should be visible to subject or monitor.
10. Accelerometers and recorders	Measurement of accelerations imparied to crewman by self or to transported masses. Sensitivity should range from 0.5 to 45.0 pfs.		32	4.0	0.8	Available model of required high sensitivity are high-cost items.
11. Depth perceptometer	Classical Howard-Dolman apparatus may be scaled down from 10 to 2 ft long to be used for measurements of angle of disparity using 0.001-in. increments. Should allow measurement of 1 to 150 sec of visula arc.	MDAC Visual-Auditory Tester	2	3.0	0.6	Conceptual design complete.
12. CRT and other displays.	CRT may be used for complex tracking, vigilance, and pattern recognition. Minimum of 4 to 5 in. diam: capable of dual input for target and cursor: 6 x 6 grid projections; probability monitoring needle gages; vigilance lights; alpha-numeric display.	MDAC COMPARE	35	40.0*	2.0	CRT should be computer-driven and scored. Should included 6 x 6 grid reference and test patterns (about 1,000), capable of higher-order pursuit tracking random inputs.
13. Display-associated controls	Items related to Item 10 above; appropriate joystick, pushbuttons for vigilance and probability monitoring, numerical entry, pattern identification.	MDAC COMPARE	5	40.0*	2.0*	Some controls may also serve as displays by transillumination.
14. Analog recorder	Must be capable of time-shared recordings of times, stimuli, responses, correct-error indication. Telemetry capability desirable. (Related to Item 10 above.)	MDAC COMPARE	30	40.0*	2.0*	Recorder flexibility must increase as does the randomness of the stimuli presented to the crewman. Primary difficulty will be tags necessary to identify stimuli and responses from several concurrent tasks.

Table 7-2 (Page 3 of 4)

Name/Function	Performance Characteristics	Available Model	Power (W)	Weight (lb)	Volume (cu ft)	Remarks
15. Orthorater	Measure visual acuity down to 0.2 arc-sec, preferably by vernier acuity technique.	Bausch and Lomb-Orthorater, Visual-Auditory Tester	2	2	0.4	If vernier acuity not feasible, minimum separable distance next best. Equipment indicated may also be employed to investigate near-static depth perception.
16. Light source	This equipment may be combined with Items 15 and 17. Used to examine: A. Figural after-effects. B. Figural masking. C. Dark adaptation; 0.00001 ml, minimum. D. Phi phenomenon: 100 to 200 msec; 2 to 12 in. E. Stereoscopic effects. F. Autokinesis. Two lights; separately controllable in frequency and intensity from 0 to 60 H_z and from 0 to 100 ft-c, with known chromaticity.	(SRT)	---	3.0	0.5	If technology permits, more detailed observations could include eve movements, convergence, shape, and size constancy.
17. Critical flicker fusion (CFF) source	Apparatus must control (possibly vary): A. Intensity of the positive phase. B. Difference between the two phases. C. Time proportion of the two phases. D. Area of flickering field. E. Part of the retina stimulated. CFF may, depending on manipulation of above variables, range from 5 to 55 cps.	MDAC Visual-Auditory Tester	5	2.0	0.4	Should apply method of limits or method of adjustment with reference to a control source.
18. Veridicality test	Illuminated bar rotable in field of vision on single plane in both directions from true vertical.	(SRT)	1	2.0	0.4	If integrated with CRT or command control, weight and volume do not apply.
19. Color plates	Pseudoisochromatic alphanumeric printed plates	Ishihara	---	0.25	0.1	
20. Pure tone source	Absolute threshold (0.0005 dynes/cm^2 at 2,000 cps) differs with frequency from -70 to +50 dB: just-noticeable pitch differences from 2 to 30 cps, depending on frequency and intensity. The differential limen for loudness also varies with frequency and	Hewlett-Packard, MDAC Visual-Auditory Tester	15	3.0	0.6	Tones must be presented by a head set. Requires programming of random stimuli for psychophysical measurement to prevent sequence learning.

Table 7-2 (Page 4 of 4)

Name/Function	Performance Characteristics	Available Model	Power (W)	Weight (lb)	Volume (cu ft)	Remarks
	intensity--most efficiency at 2,000 cps. Auditory test apparatus must consider these sensory capabilities. Requirements: 2 tone generators 0.0005 to 100 dynes/cm^2 25 to 15,000 cps					
21. Noise and vibration source	Provides vibration to evaluate somesthetic and cutaneous sensitivity. For cutaneous sensitivity: 200 to 300 H_z with 0.001-mm amplitude is generally considered to be the minimum detectable vibration, although 12,000 H_z can be detectable at higher amplitudes. For somesthetic sensitivity, sinusoidal rather than complex vibration recommended. Sensitivity and tolerance varies greatly in different body members and areas. Tolerance is least at 4 to 8 H_z.	(SRT)	20	5.0	0.9	Precise definition is required of body areas; frequency and amplitude characteristics to be investigated.
	Noise tolerance depends both on intensity and frequency characteristics, but with white noise, roughly corresponds to the Speech Interference Level (SIL), e.g., 80 dB at 1 ft. 65 dB at 10 ft.	Hewlett-Packard	---	---	---	
22. EMG sensors and recorders	Sensors: 100 to 10,000 μV: 0.5 to 5,000 H_z. Bandwidth: 2 to 15 msec.	Biomedical apparatus (IMBLMS)	2	3.0	0.6	
23. GSR and EEG sensors and recorder	GSR: 5,000 to 100,000Ω or more--variable sensitivity appropriate	Biomedical apparatus (IMBLMS)	5	5.0	0.6	
	EEG: 10 to 300 μV: 0.2 to 100.0 H_z bandwidths					EEG sensors must be attached directly to the scalp and highly amplified. Recorders for EMG, GSR, EKG, if highly sophisticated, could be combined.

Table 7-3 (page 1 of 12)

BIOSCIENCE LABORATORY EQUIPMENT DESCRIPTION

	Name/Function	Performance Characteristics	Available Model	Power (W)	Weight (lb)	Volume (cu ft)	Remarks
1.	~~Automatic~~ Automatic cell counter	0 to 7.5 x 10^6 cells per cu mm	Fisher Autocytometer (Blood Cells)	20	10	0.4	
2.	Autoclave	30 to 40 psia, 100° to 135°C	---	1,000	25	2	Possibly use small unit with less power (1,000 w).
3.	Automatic plate scanning counter	---	---	20	20	1	With automatic sample changer and paper printout.
4.	Bone desitometer	Operating range: 20 to 50 kV Exposures: 0.02 to 0.5 sec	Phillips Oralix Super 50 Dental X-ray Unit	1,000	100	2	Can be used for human limbs (not skull or torso), besides nonhuman vertebrates. Includes lead shielding. Uses slow film to avoid background fog.
5.	Movie Camera	35 mm film; frame rates between 1 hr.$^{-1}$ and 20 sec^{-1}	---	0	0	0.3	Slow emulsion film to avoid background fogging. Possible outgassing problem from Polaroid. Conceivably delete all but video cameras (different resolutions and scan rates).
6.	Plate film camera	---	---	---	---	---	
7.	Polaroid Camera	Standard 3-1/4 in. x 4-1/4 in.	---	0	2.75	0.037	
8.	Roll film camera	35 mm	---	0	5	0.1	All cameras with close-up optics compatible with microscopes.
9.	Video camera	250,000 elements, between 4 and 128 grey tones. Frame rates between 1 hr^{-1} and 30 sec^{-1}. With recorder and display.	---	160	60	2	
10.	Centrifuge, organism	0.1 x g to 1 x g.	---	50	25	1.5	For subvertebrates through mice, counterrotating design.
11.	Centrifuge, refrigerated high speed	Accommodates eight 50-ml tubes Speeds to 18,000 rpm; forces to 40,000 xg. Temperature range from -20°C to +40°C.	Lourdes Model A Beta-Fuge	2,000	200	18	May need counterrotating design to null angular momentum. Also consider microcentrifuge 0.4-ml tubes, 15,000 rpm, 100 W, 10 lb, 0.2 cu ft, Beckman Model 152 Microfuge).
12.	Clinostat	---	Conrad Design-NAA	25	8	1.2	Centrifuge included.
13.	Colorimeter	Range: 340 to 950 mμ Resolution: 20-mμ band pass.	Bausch and Lomb Spectronic 20	20	10	0.4	Dial readout (no recorder). For body fluid clinical analysis
14.	Dosimeters	Pen dosimeters (200-mr full scale) with changer. Film badges (3-mr to 600-mr full scale). Ion Chamber radiation meter.	Nuclear Chicago 401 to 405 2500 series and film badges	0	5	0.2	Gamma radiation detectors.

Table 7-3 (page 2 of 12)

	Name/Function	Performance Characteristics	Available Model	Power (W)	Weight (lb)	Volume (cu ft)	Remarks
15.	Dry heat sterilizer	150°C to 190°C range	---	50	5	0.3	For small instruments.
16.	Drying oven	Ambient to 125°C range	---	600	40	2	Possibly combined with incubator as single unit.
17.	Electroanalytical apparatus A. pH electrode, variety of platinum electrodes, mercury drop electrode, etc. B. Constant-current, controlled-voltage power supply.	Constant current selectable from 0 to 100 mA. Scan voltage ranges between ±0.5 V and ±5.0 V, with scan rates between 0.5 mV/sec and 500 mV/sec.	Beckman Electroscan 30	10	20	1	For cyclic voltammetry, chronoamperometry, controlled voltage coulametry, anodic stripping voltammetry, etc. (polarographic analyses). Includes pH and Redox measurements. Needs a recorder.
18.	Electrophoresis apparatus A. Migration chamber (paper strips) B. Power supply C. Optical densitometer	Power supply provides either constant current (2 to 50 mA) or constant voltage (0 to 500 V). Densitometer operates at wavelengths selected with interference filters (typically 500 mμ).	Beckman Model R	20	20	1	Needs a recorder.
19.	Exerciser/ergometer, primate	---	---	0	5	0.2	---
20.	Exerciser/ergometer, rodent	---	---	0	0.5	0.01	---
21.	Freezer	-20°C	---	25	5	1	---
22.	Gas bottle	2,000-psia air, hydrogen, helium	---	0	150	5	Air and hydrogen for flame photometer and hydrogen, flame detector of gas chromatograph. Helium for gas chromatograph. Safety hazard.
23.	Gas chromatograph A. Thermal conductivity detector B. Hydrogen flame detector C. Fraction collection system	Thermal control range: 40°C to 240°C. Helium carrier gas. Hydrogen flame detector has typical sensitivity of 50 parts per billion (full scale) for organic compounds (10^4 times as sensitive as thermal conductivity detector.)	Beckman GC-2A	100	10	0.6	Hydrogen flame detector needs air and hydrogen supplies. Needs helium carrier gas supply. Needs recorder.

Table 7-3 (Page 3 of 12)

Name/Function	Performance Characteristics	Available Model	Power (W)	Weight (lb)	Volume (cu ft)	Remarks
24. Histology kit/slide cabinet	---	---	0	5	1	---
25. Incubator	5°C to 60°C	---	60	20	0.7	For both experiments and paraffin sample embedding.
26. Isotope tracer equipment						
A. Isotope solutions and shielding	C-14 labeled acetate, amino acids, etc.	---	0	10	0.2	---
B. Liquid scintillation counter	---	Nuclear Chicago 6850	200	200	5	Automatic sample changer and paper printout. With shielding (more may be needed).
C. Radioautography apparatus	Slow film to avoid background fogging.	---	0	2	0.2	
27. Liquid nitrogen Dewar flask.	-100°C to -190°C depending on design.	---	0	100	2	Boiloff problem with cryogenic storage.
28. Lyophilizer	Isopentane cooled with liquid nitrogen to -160°C.	---	0	10	0.8	Uses space vacuum. Alternate cooling electrically to -60°C for 200 W, 20 lb, 1 cu ft.
29. Mass-measurement device (macro)	Measures 0.1 kg to 30 kg.	---	0	5	5.2	---
30. Mass-measurement device (micro)	Measures 0.1 g to 100 g.	---	0	1	0.2	---
31. Mass spectrometer	Detection to mass number 1,000 and 1 part per million. Unit resolution at mass 500.	EAI Quad 300 (quadruple type)	200	40	2	Uses space vacuum to eliminate pumps. Works with gas chromatograph. Needs oscillograph recorder and computer data processing.
32. Micromanipulator	Ellis piezoelectric-type	---	10	5	0.5	---
33. Microscope, compound	10X eyepiece, 25X, 10X, 40X and 100X objectives.	Zeiss Binocular Microscope, Model RA				
A. Trinocular tube			25	10	0.5	---
B. Accessories for bright-field, dark-field, polarized light, phase contrast, interference contrast, and fluorescence microscopy.						
34. Microscope, electron	50-kV 100-Å resolution Magnification: 2000X to 4000X	Japan Electron Optics Laboratory (JEOL) JEM-50	500	150	5	Uses space vacuum to eliminate pumps.

Table 7-3 (page 4 of 12

Name/Function	Performance Characteristics	Available Model	Power (W)	Weight (lb)	Volume (cu ft)	Remarks
35. Microscope, stereoscopic dissecting	2.5X to 100X magnification at 80-mm working distance. 5X to 200X at 28-mm distance.	Zeiss Stereo Microscope III (Zoom)	30	30	1	With trinocular tube and illuminator.
36. Microtome	Section thickness: 1 to 50. Ultra-thin sectioning adapter achieves 0.05- thickness.	AO Precision Rotary Microtome No. 821	0	10	0.3	Freezing attachment may need modification from CO_2. Electron microscope needs ultra-thin sections. Most applications need only 5- to 50-μ thickness.
37. Miscellaneous	---	---	50	70	3	Total.
A. Chemicals	---	---	0	7	0.3	Preservative and reagents.
B. Fluid-handling equipment	---	---	0	5	0.2	Syringes, test tubes, stoppers, etc.
C. Timers	---	---	0	1	0.1	---
D. Hand magnifier with light	---	---	20	1	0.1	---
E. Dissection/surgery/necroscopy equipment	---	---	0	5	1	---
F. Accelerometer packages	10^{-7}g to 10^{-1}g at 10^4 cps or less. 10^{-1}g to 10^3g at 10^4 cps or less	--- ---	10	5	0.1	Continuous operation.
G. Rulers, protractors, etc.	---	---	0	2	0.2	---
H. Toxicity detectors	---	---	20	20	0.2	Continuous operation.
I. Paper	---	---	0	20	0.3	Notebooks, recorder charts, etc.
38. Mixer/shaker	---	---	10	5	0.3	---
39. Polarographic CO_2 and O_2 sensors	Partial pressure CO_2: 1 to 20 mm Hg.	Beckman	0	0.3	0.1	Need amplifiers and dial readouts; probably part of electro-analytical apparatus.
	Partial pressure O_2: 0 to 1,000 mm Hg.	140732 (CO_2 sensor) 7841IV (O_2 sensor)	--- ---	--- ---	--- ---	
40. Radiation shielding	Lead	---	0	200	0.3	---
41. Radiation source	85-strontium gamma source with 180° cone of radiation. Dose levels to 2,000 R/day.	Biosatellite II (hardware)	0	5	0.2	Includes shielding and automatic open/close mechanism. Half-lite (65 days) may be marginal for long missions.

Table 7-3 (page 5 of 12)

Name/Function	Performance Characteristics	Available Model	Power (W)	Weight (lb)	Volume (cu ft)	Remarks
42. Recorder, high-speed oscillographic	---	Texas Instruments Oscillo/riter	40	20	1	Serve as output units for the spectrophotometers, gas chromatograph, electrophoreses densitometer, electro-analytical apparatus, and mass spectrometer.
43. Recorder, linear potentiometric	10-in. scale with disk integrator	Beckman 100506	40	20	1	---
44. Recorder, voice	---	---	50	5	0.3	---
45. Refrigerator	4°C	---	50	20	3	With shielded chamber for radioisotope solutions.
46. Spectrophotometer, IR	Range: 2.5 to 3.5u. Resolution better than 0.1% wavelength. Scanning time 5 sec to 50 hr. Sample temperature to 250°C with heated cell. Double beam Nichrome source. Thermocouple detector.	Beckman IR 20	250	50	2	Has a heated flow-through cell for use with gas chromatograph. Needs a recorder (oscillographic when in fast-scan mode with gas chromatograph).
47. Spectrophotometer, UV-visible	Range: 185 to 700 in Resolution: better than 0.1% wavelength.	Beckman DK-2A	10	5	1	Does not include recorder. Flame photometer needs air and hydrogen supplies (detects alkali metals: typically sodium, potassium, and calcium).
A. Flame photometry attachment	Scanning time: 3 min. to 5 hr. Dougle beam, ratio recording. Tungsten and hydrogen lamp sources. Lead sulfide cell and photomultiplier tube detectors.					
B. Reflectance photometer attachment						
48. Ultrasonic cleaner	Operates at 20 kHz (and/or others) with piezoelectric transducers.	---	30	20	1	With tanks, cleaner fluid, and other accessories
49. Vacuum desiccator	---	---	0	10	2	Reclaims water with cold trap. Uses space vacuum. Probably combined with lyophilizer.
50. Veterinary medical kit	---	---	0	5	1	Includes otoscope/ophthalmoscope, reflex hammer hemoglobinometer, tourniquet etc.

Table 7-3 (page 6 of 12)

Name/Function	Performance Characteristics	Available Model	Power (W)	Weight (lb)	Volume (cu ft)	Remarks
51. Primate calorimetry module (sealed adiabatic chamber)	Contains one instrumented, 20-lb male, adult, pig-tailed macaque monkey (Macaca nemistrina) and EC/LS and biologic fluid subsystems for a 90-day experiment.	Laboratory envelope, structure (McDonnell) for UC Berkeley APRL	70	90	230	Two such modules required. These sealed calorimetric primate capsules subserve the primate metabolism and primate hemodynamics experiments. CO_2 absorbed by LiOH (32 lb). Food and water mixed in a slurry.
A. Oxygen supply	140 ℓ/day for 90 days	---	---	40	---	
B. Nutrient supply	900 g/day for 90 days.	---	---	180	---	
C. Nutrient dispenser	---	---	---	---	---	
D. Urine-collection subsystem	---	---	---	TBD	---	
(1) Urethral catheters	---	---	---	---	---	
(2) Urine pump	---	---	---	---	---	
(3) pH meter	---	---	---	---	---	
(4) Pressure sensor	---	---	---	---	---	
(5) Relief over-pressure	---	---	---	---	---	
(6) Flow meter	---	---	---	---	---	
(7) Automated urine analyzer	10% of total urine volume analyzed JPL unit in flight	---	---	---	TBD	Analyzes calcuim creatinine, and creatine.
(8) Urine-storage freezer	---	---	---	---	---	
(9) Temperature sensor	---	---	---	---	---	
E. Feces-collection subsystem	---	---	---	---	TBD	
(1) Flatus-gas remover	---	---	---	---	---	
(2) Solid-feces storage freezer	---	---	---	---	---	
F. Automated hemo-dynamic subsystem	---	---	---	---	TBD	
(1) Vascular catheters	---	---	---	---	---	
(2) Withdrawal and infusion syringes	---	---	---	---	---	
G. Pressure transducer	---	---	---	---	---	
H. Optical densitometer	Measure density at 805μ	---	---	---	---	
I. Optical densitometer	Measure density at 660μ	---	---	---	---	
J. Refractometer	Measure refraction at 805μ	---	---	---	---	

Table 7-3 (page 7 of 12)

Name/Function	Performance Characteristics	Available Model	Power (W)	Weight (lb)	Volume (cu ft)	Remarks
K. Pump, mechanical drive	---	---	---	---	---	
52. Primate geodesic module	Contains one instrumented chimpanzee (25 to 40 lb) and EC/LS, waste-management, and neurophysiologic test equipment for a 60- to 120-day experiment.	Laboratory envelope structure (Adey-UCLA, Mechan-USC)	700	70	180	Two such geodesic spheres required: one chimp restrained, unrestrained. The two modules subserve the primate behavior and the primate bioghythms experiments. (Total PCM: 10 MH_z.)
A. Electroluminescent house lights	---	---	100-150	10	---	6.5-sq ft total surface area. LiOH (32 lb) to absorb CO_2. Food and water mixed in a slurry. Air-flow and wiperblade action.
B. Oxygen						
C. Nutrient supply						
D. Nutrient dispenser						
E. Waste-management subsystem						
F. Ergometric joystick manipulanda						
G. Speaker for tone generator						
H. Stereo-binocular microscope with rheostat-controlled incident illuminator	Low to high stereomagnification.	Zeiss Instruments	---	---	---	Can visualize microcirculation of blood in scleral conjunctival vessels of eye. (This apparatus may better subserve the macaque monkey hemodynamic experiment than the chimpanzee biorhythms experiment.)
53. Mouse reproduction module (with central nesting area)	---	---	5-7	180	10	Pressurized to 14.7 psi; 20% O_2/80% N_2, CO_2 absorbed by LiOH, Air flow rate 6 cu in./min.
A. Oxyten supply						
B. Nutrient supply						
(1) Food pellets						
(2) Water						
C. Nutrient dispensers						Forms part of the "hat" of chamber
D. Water dispenser						
E. Video wide-angle camera						

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Name/Function	Performance Characteristics	Available Model	Power (W)	Weight (lb)	Volume (cu ft)	Remarks
54. Mouse calorimetric module	Precise heat-production measurements.	---	---	---	---	Sealed adiabatic chamber.
Rodent exerciser	Ergometrically programmed with timers.					
55. Pocket-mouse housing unit with ECS, data-handling, and -storage. Battery for interior power for ECS operation during launch, ascent, and OWS setup integrated into common package for unitary mounting and operation.	Six animal tubes enclosed in a container with antennas and receivers for each tube. ECS provides atmospheric composition and experiment temperature control for up to 30 days in space. Earth atmosphere of N_2 and O_2 provided, with H_2O vapor and CO_2 concentration controlled.	Northrup (Dr. Lindberg)	75	70	5.2	Used for circadian rhythm study. Ideal duration of biorhythm experiments would be 90 days or more. Connections will be required for electric power and telemetry system. Experiment package will require space-radiator service from the carrier
56. Fish aquarium	Modified for air volume control in orbit. Must be capable of sustaining small aquatic vertebrate fishes (e.g., guppies) in a weightless environment. (Note: A larger aquarium may be required for the flounder (genetics) experiment.)	TBD	10	25	0.5	Four fish experiments, each requiring aquarium facilities. (Note: Some of the invertebrate experiments, e.g., Planaria (flatworm) studies also require aquarium facilities.)
Aerator	Modified for orbital conditions.	TBD	10	---	---	---
57. Daphnia (water flea) containers. (Note: Each 60-ml sealed container holds four pregnant Daphnia pulex and their offspring (7 to 30 per container: oxygen-saturated medium No. 39; also Chlamydomonas (algal food).	Three containers of 60-ml volume each comprise the flight package for one experiment. The cylinders may be placed in line or clustered. Thermal constraints for each cylinder: A. 18°C minimum and 22°C maximum for operating temperature limits; B. 5°C minimum and 25°C maximum for storage temperature limits of each assembly.	Present state issue of standard 60-ml laboratory vials with screw caps (each vial with cap). (Note: NASA Ames Research Center is developing similar containers.)	None	0.66	15.5	Three Daphnia experiment categories exist. All three cylinders of a flight package should be exposed to the same vibration and gravity forces. (Note: Each container is a cylinder with 4-3/4-in. x 1-in. x 1-in. dimensions.)

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Name/Function	Performance Characteristics	Available Model	Power (W)	Weight (lb)	Volume (cu ft)	Remarks
	Medium No. 39 contains precipitate $CaCO_3$ concentration of algae 1 x 10^6 cells/ml.					
	(Note: Oxygen and food supply become the major limiting factors during sealed experiments. The animals will tolerate pO_2 within the range of 740 to 74 mm Hg.)					
58. Automatic physiological gas analyzer	pO_2, pCO_2 and pH must be monitored on controls. Automatic measuring and recording features have been built but require testing.	Prototype modified for small aquatic chambers by Derek Engstrom, U of Wash.	10	5	0.25	See NASA grant NsG-519.
59. Insect chamber (general)	Growth and reproduction maintained. Visual and photographic observation.	---	---	---	---	For cockroach behavior, biorhythm, amoeba parasite (or termite symbiosis), and possibly ant-behavior experiments. Drosophila (vinegar gnat) facility should separate from the general insect chamber.
A. Illumination source with timer.	Day-night cycle reversible.	---	---	---	---	
B. Drosophila (vinegar gnat) facility (excluding circadian rhythm--vinegar gnat pupal eclosion experiment)	Maintain temperature range of: 15°C to 26°C	---	None	4	0.01	Special insect chamber for five of the six Drosophila experiments. The Drosophila circadian rhythm experiment requires a specialized chamber for the pupal stage of the vinegar gnat.
	Atmosphere: Standard temperature and pressure	---	---	---	---	
	Humidity: 40 to 80%	---	---	---	---	
	Temperature profile required.	---	---	---	---	
Approximately 96 cells (chambers)	---	---	---	---	---	The facility described, although designed primarily for genetic studies, can also subserve the morphogeo-sensitivity, metabolism, and behavioral experiments with modifications for observations of adult specimens.
Air to be supplied to the cells by the capsule gas-management system.	Individual respiratory requirements for eggs, larvae, and papae--an average of 0.004 cu ml/hr/individual.					
Each cell will contain approximately 400 individuals, for a total of 7,200 organisms.	The grouping in individuals per cell will be 100 eggs, 100 first instar larvae, and 100 pupae.	---	---	---	---	

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Name/Function	Performance Characteristics	Available Model	Power (W)	Weight (lb)	Volume (cu ft)	Remarks
60. Drosophila (vinegar gnat) biorhythm module	Package consists of four experiment chambers held at 5°C constant darkness until initiation of experiment in space. Two of the chambers will be brought slowly to 10°C and two slowly to 20°C. Then light cycling will be imposed, and rate of eclosion (emergence) of papae measured.	---	21	32	2.8	The circadian rhythm package, as designed, does not require return to Earth. Extraneous cyclis events should be minimized.
61. Flatwork (Planaria) container	Temperature: 65° to 80°F. Oxygen to be dissolved in the water. Food: lyophilized sterile liver homogenates suspended in the water medium.	---	None	30	0.5	The package can be sectioned into two halves, one being shielded from radiation.
62. Ant growth chambers	See insect chamber, general.	---	---	---	---	See insect chamber, general.
63. Amoeba culture container, chemostat, and pump	---	---	25	7	0.5	The amoeba culture containers may also subserve the dinoflagellate and possibly the neurospora (fungus) environmental culture requirements, with some modifications. The human-cell culture experiments have a special package environment.
64. Frog-egg flight package	Each package contains 12 modules	General Electric is constructing breadboard.	15 (avg)	40	1.6	Three frog-egg flight packages required.
A. Frog-egg module	Each module contains three units.					36 modules required.
B. Frog-egg unit	Each unit contains frog eggs and sperm.					108 frog-egg units required.
(1) One egg chamber	20 cc, 100% relative humidity 20 frog eggs (initial)	---	---	---	---	(Note: Unanticipated lengthened hold time would be of concern because low temperature will not maintain acceptable rates of fertilization indefinitely. If experiment flies on a mission longer than 4-1/2 days, all the embryos can be fixed and returned up to 2 weeks after launch.)
(2) One sperm-solution chamber	20 cc capacity	---	---	---	---	
(3) Two (or more) wash chambers	---	---	---	---	---	
(4) One media chamber	(spring water)	---	---	---	---	
(5) One fixative chamber	---	---	---	---	---	

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Name/Function	Performance Characteristics	Available Model	Power (W)	Weight (lb)	Volume (cu ft)	Remarks
(6) One waste chamber	---	---	---	---	---	
Note: Flights longer than 3.25 days require: 12 to 15 sq ft bench space 1 refrigerator 1 microphotographic apparatus 1 sink 1 transport case	Note: Each experiment package to maintain eggs and sperm at 5° to 10°C during hold time, and at 18°C during orbit; temperature readout by thermistor at modular level (four readouts) continuous to ground. Readout range: 5° to 25°C.					
65. Bacteria culture chemostat with transfer device and pump	---	---	25	5	0.5	
66. Bacteriophage flight package	---	---	25	11.5	0.3	This bacteriophage package is a modification of the frog-egg experiment flight package.
67. Human cell experiment flight package consisting of:	---	Woodlawn Wanderer Nine-A, Texas Instruments, Inc.	7.5	17.6	0.45	
A. Microscope-camera system						
(1) Camera No. 1	40X magnification optics	---	---	---	---	12,000 pictures at five pictures/min.
(2) Camera No. 2	20X magnification optics					12,000 pictures at five pictures/min.
(3) Microscope	Phase contrast optics with adjustable focus.					
B. Biopack system, consisting of four identical biopack subsystems	Each biopack subsystem consists of two epoxy disks, one a "media" and one a "specimen" disk.	---	---	---	---	
C. Temperature-control system (canister is sealed metal enclosure)	Maintains all specimen slides at 98.6°F (-4°F - 1°F): canister maintains all experiment equipment in a sealed 14.7-psia air environment.	---	---	---	---	

Table 7-3 (page 12 of 12)

Name/Function	Performance Characteristic	Available Model	Power (W)	Weight (lb)	Volume (cu ft)	Remarks
D. Human-cell culture chamber storm cellar	Offers radiation protection (37.5°C)	---	20	20	0.1	
E. Refrigerated storm cellar	(-40°C)	---	50	42	0.13	
68. Plant growth chamber with temperature and humidity controls	Must have dark-chamber capabilities. Radiation source and dosimeters may be required within the chamber.	---	50	100	2.25	
69. Plant growth chamber (radiation-shielded)	Same requirements as unshielded chamber.	---	50	150	2.25	
70. Seedling culture tank	Lucite; 36.5 x 3.5 x 4.3 in.	---	---	---	---	
71. Seed culture tank	Lucite; 36.5 x 2.5 x 2.5 in.	---	---	---	---	
A. Nutrient pump	---	---	15	2	0.10	
B. Air blower	---	---	15	2	0.25	
C. Artificial light	---	---	200	0.25	0.25	

Table 7-4 (page 1 of 7)

LIFE-SUPPORT-SYSTEM LABORATORY EQUIPMENT REQUIREMENTS

Name/Function	Performance Characteristics	Available Model	Power (W)	Weight (lb)	Volume (cu ft)	Remarks
1. Test specimen	See life support experiment summary sheets in Appendix A.	Experiments 4-1 to 4-58	---	---	---	See experiment summary sheets in Appendix A.
2. Microbial Laboratory	---	---	---	---	---	Major microbial laboratory equipment required is given in Biomedical List.
3. Chemical laboratory						
A. Gas chromatograph with flame detector	Frequent scanning of cabin air for organic contaminants.	NASA/MSC Unit Built by MELPAR	10	12	0.5	Apollo technology.
B. Mass spectrometer	Identifies trace gases not identifiable by gas chromatograph; measurements to a fraction of 1 ppm required.	Bendix "Time of Flight" Mass Spectrometer	Unknown See Remarks	150	12	Commercial unit. A flight type unit should be developed to weigh 20 lb and have a volume of 1.5 cu ft and a power of 30 to 50 W.
C. pH meter	Measures the pH of reclaimed water; range: 1 to 15 pH.	None	1	1	0.005	Development required.
D. Electrical conductivity meter	Measures specific conductivity of solution; range: 0 to 10,000 µmhos/cm.	None	None	2	0.01	Development required.
E. Calorimeter or Coleman spectrometer, junior model	Measure absorption from 3,000 to 7,000 Å.	None	10	3.5	0.05	Development required.
F. Turbiditimeter	Compares turbidity of solution against standards produced with SiO_2; range: 0 to 150 Jackson units.	None	5	5	0.10	Development required.
G. IR spectrophotometer nondispersive.	Measures trace contaminants less than 0.1 ppm.	Beckman or P. E. Instrument	30	100	2.0	Commercial model miniaturized (SRT).
H. Mass-measurement device	Range, large masses: 200g to 100 kg Range, small masses: 1µg to 200 g.	Lockheed USAF/AMD	Unknown	Unknown	Unknown	Available 1968.
I. Illumination device	Standard three-cell flashlight.	Flashlight	2	0.25	0.5	Available.
J. Aerosol particle analyzer	Separates particles in the 0.2- to 10.0-µ range into five groups and counts particles in each group.	Miniaturized model constructed by NASA ERC.	Battery operated	10	0.5	Each battery good for 160 runs: not rechargeable.

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Name/Function	Performance characteristics	Available Model	Power (W)	Weight (lb)	Volume (cu ft)	Remarks
K. Total aerosol collector	Collects all particle sizes; counts total dust loading by microscope.	Miniaturized model constructed by NASA ERC.	Battery operated	10	0.5	Under development.
L. Water analysis by total organic carbon (TOC)	Potability of water TOC range: 2 to 75 mg/1.	Commercial Model Beckman	15	25	1.0	Should be miniaturized.
M. Total hydrocarbon analyzer, dispersive	Continuous monitoring of cabin; range: 1 ppm to 10%	MSA, Lira Analyzer	25	20	1.5	Could be miniaturized.
N. MSA indicator tubes and handpump	Ammonia, oxides of nitrogen, SO_2, sensitive to less than 1 ppm.	Mine safety appliances	Hand operated	2	0.1	---
O. Ignition device	Spark ignition electrodes and transformers; ranges: 20 to 30 mA at 7,000 ± 500 V and 20 to 70 amps at 1 to 5 V.	Special equipment	140 to 350	20	0.1	Ignition device located in a 75-liter flask.
P. Fire detector	To detect visible and invisible smoke or products of combustion in cabin.	Miniaturized unit similar in principle to Pyrotronics, Inc., Pyralarm, Model No. DIS-5 5AR5B.	500	5	1.0	Weight, volume and power given for predicted miniaturized unit; 500-W peak required instantaneously to activate relay.
Q. Fire-extinguishing agents	Diluent (nitrogen or helium), CO_2 and H_2O source (2 lb bottles).	None	None	2.5	0.1	Weight and volume are given for one experiment.
R. Optical pyrometer	Flame-measuring range; 900° to $5,500^{\circ}$F.	Specially built unit comparable to those manufactured by Milletron.	50	5	0.5	Development required for flight-type unit.
4. Work bench for maintenance and repair	Restraints for equipment and personnel. More than one may be used, depending on allocation of various experiments.	Orbital Workshop Experiment No. M50B, to be used as model or one of many.	50	40	80	Part of vehicle design.
A. Log book	Fireproof paper.	Apollo Program	None	5	0.5	Applied Apollo technology.
B. Tools for maintenance and repair	Hand tool kits, tools, and tool tethers.	Special Equipment	None	18	0.6	Development required.
5. Radiation laboratory	(See Table 7-1 and 7-3)		---	---	---	---
6. Ergometer	(See Table 7-1 and 7-2	Orbital Workshop Experiment No. M-050	15	30	5	Flight unit under development.
7. Tether	60-ft long, to be attached to rings on crewman suit waist.	Apollo Block II Type	Not applicable	5	0.2	Available from Apollo and AAP.

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Name/Function	Performance Characteristics	Available Model	Power (W)	Weight (lb)	Volume (cu ft)	Remarks
8. Umbilicals	60-ft long, 1 in. diam, delivers O_2/hr at 3.69 psi; includes water, O_2, and electrical lines.	Apollo Block II type	Not applicable	33	3	Available from Apollo and AAP.
9. EC/LS back-pack	Provides 3.8-psia O_2, removes CO_2, and circulates cooling water to under-garment for 4 hr. Also includes control equipment.	Apollo/Hamilton Standard	240 W	84	4.5	Apollo technology.
10. Special clothing	0.25, 0.5, 0.75 and 1.0 Clo values.	Custom-made	Not applicable	1 to 3	0.3	Existing technology.
11. Space suits						
A. Soft suit	3.7-psia suit/5 to 7-psia cabin.	Apollo Pressure Suit	Not applicable	61	8.5	Existing technology.
B. Hard suit	3.0- to 7.0-psia suit/7-to 14.7-psia cabin.	NASA Ames AX-1 or AX-2	Not applicable	65	8.5	Adaptation of existing technology.
12. Biomedical monitoring equipment	See Table 6-1.		---	---	---	Development required.
13. Metabolic measuring device	Register 0 to 6.61 at 0 to 80 l/min.; pO_2: 0 to 2.5 psi; CO_2: 0 to 1.5 psi; core temperature sensitivity: 98° to 101°F; skin: 50° to 115°F; EKG: 300 to 5,000 μ V; band width: 0.5 to 50 H_z.	(See Table 7-2)	None	4	1	Development required.
14. Leak detector	Gas: 1 to 10 x 10^{-6} lb/hr at 50 to 150 psig. Liquid: 1 to 10 x 10^{-4} lb/hr at 20 to 60 psig.	None	5	5	0.4	One method proposed: monitoring usage rate.
15. Wattmeter	Ranges: 0 to 100, 0 to 500, 0 to 1,000, 0 to 3,000 W. Accuracy ±1% of full scale.	Specially miniaturized equipment	None	0.5	0.1	Development required.
16. Voltmeter	Ranges: 0 to 10, 0 to 50, 0 to 100, 0 to 200, 0 to 500 V. Accuracy ±1% of full scale.	Specially miniaturized equipment	None	0.5	0.1	Development required.
17. Ammeter	Ranges: 0 to 1,000 mA and 0 to 5, 0 to 10, 0 to 50 amps. Accuracy ±1% of full scale.	Specially miniaturized equipment	None	0.5	0.1	Development required.

Table 7-4 (page 4 of 7)

Name/Function	Performance Characteristics	Available Model	Power (W)	Weight (lb)	Volume (cu ft)	Remarks
18. Pressure sensor	Gas: 0 to 0.1 psia to 0 to 200 psia	Rosemount PN 830A	---	1.2	0.01	Applied Apollo technology.
	Liquid: 0 in. Hg to 30 in. Hg up to p to 5,000 psig.	Robinson-Halpern PN P61	---	0.77	0.007	
19. Temperature sensor	Gas: 20° to 90°F.	Apollo PN 836950	---	0.2	0.001	Requires amplifier: Apollo PN 836050, 0.3 lb, 0.005 cu ft.
	-445° to 500°F.	Rosemount PN 150MA	---	0.25	0.001	Requires amplifier: Rosemount 510AF, 0.55 lb, 0.004 cu ft.
	Liquid: -50° to 100°F.	Apollo PN 836058	---	0.4	0.002	Requires amplifier: PN 836056 (above).
	-445° to 930°F.	Rosemount PN 177MA	---	0.25	0.001	Requires amplifier: PN510AF (above).
20. Flowmeter	Gas Flow: 0.04 to 0.3 lb/hr up to 0.3 to 3.0 lb/hr	Apollo Series 5000	None	0.38	0.0025	Requires converter, Apollo Item No. 6.58 which weighs 0.52 lb, volume 0.01 cu ft.
	Gas Flow: 0.36 to 6.4 lb/hr up to 10 to 160 lb/hr	Apollo Series 5000	None	0.165	0.015	
	Liquid Flow: 50 to 375 lb/hr up to 300 to 4,750 lb/hr	Apollo Series 5000	None	0.38	0.0025	
21. Humidity sensor	1 to 1,000 ppm by volume range, equivalent to -101 to -5°F. Accuracy: ±5% of full scale.	CEC type 26-350	10	35	1	Commercial unit, should be made flight type to weigh about 2 to 3 lb; power approximately 1 to 2W.
22. Dew point meter	-100° to 0°F range	Cambridge Model 92	880	60	4	Commercial unit (refrigeration included)
	0° to 100°F range	Technology, Inc., Model 707 Thermoelectric	120	18	0.5	Commercial unit, Flight-type unit should weigh about 10 lb and require less than 30 W when developed.
23. Timer	0 to 24 hr; 0.01-sec accuracy sweep second hand; time out; portable; capable of hand or electronic pulse control.	MDAC-COMPARE	---	1.0	0.02	Capable of intermittent use without reset.
24. Movie camera	1 to 200 fps; single frame exposure; range finder; 16 mm or larger; zoom, wide angle, and telephoto lens; cartridge load; automatic exposure selectric; pop-up external viewfinder; film remaining indicator.	Bolex	200	3.0	0.2	All controls should be operable in the pressurized pressure garment assembly (PGA). Light source must be included.

Table 7-4 (page 5 of 7)

Name/Function	Performance Characteristics	Available Model	Power (W)	Weight (lb)	Volume (cu ft)	Remarks
25. Still camera	35 mm or larger (single-lens reflex); automatic exposure select, wide-angle, telephoto and close-up lenses; one-hand operation.	Hasselblad	None	1.5	0.2	Include strobe-type flash and variety of film: color, black and white, high-contrast, high-speed, etc.
26. Pumps	Liquid Pump: 200 lb/hr at specific gravity = 1:100°F temperature and 30-psi pressure rise.	Apollo PN 850024-5	36	2	0.01	Adaptation of Apollo technology.
	Liquid/solid pump: flow rate 20 to 200 lb/hr.		50	10	0.02	
27. Fans	30 to 150 cfm at 7 psia and 0.4 to 0.15 in. H_2O pressure rise.	Apollo PN 826010-2 and 826070-3	19	1.5	0.01	Adaptation of Apollo technology.
28. Blowers	20 to 35 cfm at 7 psia, 10- to 12-in. H_2O pressure rise.	Apollo PN 826000-2	85	5	0.10	Adaptation of Apollo technology.
29. Accelerometer	Measurement of small accelerations of the vehicle, on-board crewman and masses, Acceleration levels of 0 to 3 g.	None	Not applicable	4	0.8	Applied Apollo technology.
30. Velocity meter	0 to 50 fps gas velocity, accuracy ±1% of full scale.	Heated thermister anemometer	1	0.1	0.001	Development required.
31. Liquid gaging unit	0 to 1, 0 to 10 and 0 to 200 lb/hr at specific gravity = 1, accuracy ±1% of full scale.	Rotary displacement meter	None	1	0.01	Development required.
32. Radioisotope shielding	Included as part of test specimen and/or power unit.	---	---	---	---	50 rem maximum total dosage allowable to crewmen.
33. Gas compressor	Multistage compressor with a pressure range of 0 to 3,000 psi.	---	500	20	1.0	Development required.
34. Accumulator	Spherical stainless-steel tanks	---	None	2	1.0	Applied Apollo-Gemini technology.
35. Holding tanks	Two bladder tanks, nitrogen or helium pressurizing fluid, 1-cu ft capacity each.	---	None	5	2.0	---
36. Special space radiator	Required for such experiments as the reversed Brayton cycle reliquefaction system. Thermal energy to be rejected about 500 W.	---	20	30	---	Liquid/vapor problem in null gravity. Radiator area--32 sq ft.

Table 7-4 (page 6 of 7)

Name/Function	Performance Characteristics	Available Model	Power (W)	Weight (lb)	Volume (cu ft)	Remarks
37. Cryogenic supply	5-lb capacity, liquid nitrogen, special insulation, liquid delivery of cryogen.	---	5	7	1.0	Applied AAP technology.
38. CO_2 sensor	0 to 20-mm Hg range, accuracy ±1% of full scale.	Beckman CO_2 partial pressure sensor	1	2	0.1	Available technology.
39. Isotope heater	Operating temperature ranges: $200^o \pm 20^oF$, $600^o \pm 50^oF$ and $1,400^o \pm 200^oF$; energy levels: 100 ± 5 thermal watts per capsule.	AEC, Division of Isotopes Development	---	80/kW	0.2/kW	Approximate weight and volume based on use of 238 PuO_2 isotope. Power System waste heat is required.
40. Emergency backup EC/LS	(See experiment requirements summary for Experiments 4-1 and 4-2 in Appendix A.)	Apollo, Gemini, etc.	---	---	---	Must be flight-qualified hardware.
41. Reflectometer	Reflectance ρ_λ 0.8 accuracy = $\pm 3^\sigma$ = ±3% Reflectance ρ_λ 0.1 accuracy = $\pm 1^\sigma$ = ±1% Wavelength $\rho < 2\mu$	---	50	10	0.5	Development of a miniaturized spaceflight unit is required. Assumed weight volume and power are for flight equipment.
42. Optical density sensor	Optically measures density of cryogenic fluid. Device includes a light beam source and a means of measuring absorption of light passing through the cryogenic fluid. Range of absorption: 0.0001 to 1.0, with accuracy of ±0.1%.	---	50	20	1.0	A special flight-type unit must be developed.
43. Test container with bladder	Stainless-steel cryogenic container, bladder compatible with cryogenic temperatures. Pressurizing inert gas and gas source included.	---	None	1.5	0.5	Hardware feasibility based on AAP technology. Additional development required.
44. Pressure controller	Inlet pressure: 150 to 1,000 psig. flow: 10 to 100 cc/min. of nitrogen.	---	None	1.0	0.01	Based on Apollo technology.
45. Plastic squeeze container	Container volume 0.5 cu ft. pressurization requirement = 20 psig ±2 psi.	---	None	0.2	0.5	Commercial-type units, if available, may be modified and used for this purpose.
46. Heating element	Electrical heating element, supplied with a variac to control the electric energy input to the field.	---	500	1.5	0.5	Modified commercial hardware may be used in developing this unit.

Table 7-4 (page 7 of 7)

Name/Function	Performance Characteristics	Available Model	Power (W)	Weight (lb)	Volume (cu ft)	Remarks
47. Orientation device	Artificial horizon gyroscope, with readout showing position error in degrees, accuracy ±1°.	---	50	3	0.1	A modified Gemini artificial horizon may be used for this purpose.
48. Photo cell	Photocell-amplifier-relay assembly, 500 ± 10 counts per minute, 2 in. object interrupting light meter.	---	10 to 500	1.5	0.05	Power of 500 W needed intermittently to energize relay. Unit assumed to be miniaturized version of presently available devices (example Worner Models M-26, M-36 and 67).
49. Oscilloscope	Laboratory-type 5-in. oscilloscope built-in voltage regulator, recurrent sweep. Narrow-band sensitivity 10 mV/in rms; rise time: 0.07 ± 0.02 sec.	Requires miniaturization of commercially available units.	25	10	0.1	Assumed weight, volume, and power for flight-type unit. (Commercial hardware Hickok model 770A laboratory oscilloscope.)
50. Comfort simulator	Specially constructed two-man chamber; men placed on net hammocks, blower circulates air from plenum through diffusers to chamber and returns through double walls; temperature-control switches for each subject.	MDAC design	200	150	160	Development for flight-type qualification is required.
51. Pretreatment unit	A chemical-solution dispenser dispenses a preset amount (1.0 cc ±5% when actuated. Includes a mechanical counter.	MDAC design	None	1.5	0.2	Unit dry weight given, requires development for flight-type qualification.
52. Debris disposal	Incinerator utilizes electrical energy for ignition; unit capacity 1.0 lb.	Design by General American Research Division, Niles, Ill.	300	5	1.5	Prototypes of similar units have been made. Development of unit is required.
53. Vacuum cleaner	Battery-operated conventional unit.	Design by Whirlpool Corp., Systems Division, St. Joseph, Mich.	5	3	0.5	Power given for recharging batteries; unit needs development for qualification.
54. Solid/gas separator	Separates solid particles from gas stream. Uses centrifugal action; gas exits through center, solids go to circumference. Flow: 0 to 50 cfm of gas; particle sizes 10 to 1/4-in.	---	20	1.0	0.01	Similar to centrifugal gas/liquid separators but requires development regarding disposal of solids from periphery of unit.

Appendix

MATRIX CHARTS

Table A-1 (page 1 of 6)

BIOMEDICAL EXPERIMENTS AND MEASUREMENTS

EXPERIMENT TITLE	MEASUREMENTS: OCULAR COUNTER-ROLLING	OCULOGRAVIC ILLUSIONS	OCULOGYRIC ILLUSION	NYSTAGMUS	EYE-MUSCLE BALANCE	TASK PERFORMANCE	ELECTROENCEPHALOGRAPHY	EVLH	TEMPERATURE	ELECTRICAL DISCHARGE
1-1 HEAD MOVEMENT DURING ROTATION			●	●	●	●	●	●		
1-2 OTOLITH AND SEMICURCULAR CANALS	●	●	●		●	●	●	●		
1-3 ALTERED DAY-NIGHT CYCLES ON LITTER SIZE (RATS) AND EEG (CATS)						●	●		●	
1-4 RESTING DISCHARGE OF VESTIBULAR RECEPTOR CELLS IN PRIMATES							●			●

Table A-1 (page 2 of 6)

EXPERIMENT TITLE	SPIROMETRY	PHONOCARDIOGRAPHY	ARTERIAL BLOOD PRESSURE	VENOUS PRESSURE	HEART RATE	ELECTROCARDIOGRAPHY	BALLISTOCARDIOGRAPHY	CARDIAC OUTPUT	PLASMA VOLUME	CIRCULATION TIME	BLOOD VOLUME	HEMATOCRIT/RBC MASS	MASS	PLETHYSMOGRAPHY	VENOUS ARTERIAL FILLING TIME	EC FLUID VOLUME	BODY VOLUME	EXPIRATORY pO_2, pCO_2	TEMPERATURE	ELECTROENCEPHALOGRAPHY	TOTAL BODY WATER	RIGHT ATRIAL PRESSURE	RIGHT ATRIAL pO_2	URINARY CATECHOLAMINES	BLOOD CATECHOLAMINES	INTRAVASCULAR BLOOD PRESSURE	URINALYSIS	ELECTRICAL ACTIVITY	ESOPHAGEAL ACTIVITY	VENOUS pO_2, pCO_2
1-5 CIRCULATORY RESPONSES		●	●		●	●		●		●																				
1-6 BLOOD DISTRIBUTION EFFECTS ON ARTERIAL PRESSURE CONTROL			●		●	●																		●	●					
1-7 VENOUS COMPLIANCE CHANGES					●									●																
1-8 CARDIAC DYNAMICS		●	●			●	●	●																						
1-9 INTRAVASCULAR BLOOD PRESSURE			●																							●				
1-10 LOWER-BODY NEGATIVE PRESSURE DEVICE	●		●		●	●		●						●						●										
1-11 ON-BOARD CENTRIFUGE	●		●		●	●		●						●				●	●	●										
1-12 OCCLUSIVE CUFF RESPONSE	●		●		●	●		●						●				●	●											
1-13 CAROTID SINUS SENSITIVITY	●		●		●	●		●						●																
1-14 ARTERIOLAR REACTIVITY			●											●	●															
1-15 BLOOD AND BODY FLUID VOLUME CHANGES									●			●	●			●	●				●						●			
1-16 PRIMATE CAROTID BARORECEPTOR ACTIVITY			●	●	●	●					●	●						●	●									●		
1-17 DIRECT CARDIAC OUTPUT VERSUS INDIRECT METHODS	●		●	●	●	●		●		●	●	●	●					●	●			●	●							
1-18 RESPONSE TO SHOCK THERAPY	●		●	●	●	●		●		●	●	●	●					●	●			●	●						●	●

Table A-1 (page 3 of 6)

EXPERIMENT TITLE	RESPIRATION RATE	STD RESPIRATORY VOLUMES	MAXIMUM EXPIRATION FLOW RATE	ESOPHAGEAL PRESSURE	EXPIRED AIR pO_2, pCO_2	BREATH-HOLDING TIME	ARTERIALIZED VENOUS BLOOD pH, pO_2, pCO_2	VENOUS BLOOD VICARBONATE	HEMOGLOBIN O_2 SATURATION	TEMPERATURE	TISSUE PATHOLOGY	WBC COUNT	MOTILITY	ABSORPTION RATES	STOMACH VOLUME	STOMACH CONTRACTION FORCE	GASTRIC pH	AIRWAY RESISTANCE	MAXIMUM INSPIRATORY, EXPIRATORY PRESS.	HEMATOCRIT	MASS	HUNGER PAIN
1-19 PULMONARY MECHANICS	●	●	●	●	●													●	●			
1-20 CONTROL OF RESPIRATION	●	●	●		●	●	●	●	●													
1-21 BLOOD GAS EXCHANGE	●	●			●		●	●	●													
1-22 LUNG CLEANSING IN RATS										●	●	●										
1-23 INDUCED PULMONARY INFECTIONS IN MICE										●	●	●								●		
1-24 RECOVERY RATE FROM NONINFECTIOUS LUNG TRAUMA IN RATS										●	●	●										
1-25 INTESTINAL ABSORPTION														●							●	
1-26 MOTILITY AND pH													●		●	●	●					●

Table A-1 (page 4 of 6)

	MEASUREMENT																																													
EXPERIMENT TITLE	BODY TEMPERATURE	BODY MASS	BODY VOLUME	EXPIRATORY pO_2, pCO_2	INSPIRATORY pO_2, pCO_2	BLOOD VOLUME	PLASMA VOLUME	RBC MASS	EXTRACELLULAR FLUID	TOTAL BODY WATER	BLOOD UREA NITROGEN	BLOOD GLUCOSE	BLOOD FREE FATTY ACIDS	SERUM ELECTROLYTES	SERUM CREATININE	SERUM CALCIUM	SERUM PHOSPHORUS	SERUM ALKALINE PHOSPHATASE	SERUM PROTEINS	SERUM (BLOOD) pH	URINALYSIS	URINE CREATININE	URINE CALCIUM	URINE PHOSPHORUS	URINE OSMOLALITY	URINE TITRATABLE ACIDITY	URINE GLUCOSE	URINE NITROGEN	URINE VOLUME	URINE CULTURE	FECAL MASS	FECAL CALCIUM	FECAL PHOSPHORUS	FECAL NITROGEN	HISTOLOGY	CALCIUM TURNOVER RATE	BONE FORMATION RATE	BONE DENSITY	MUSCLE SIZE	URINE CREATINE	ELECTROMYOGRAPHY	BLOOD LACTIC ACID	MUSCLE STRENGTH	WBC COUNT	SPECIMEN MASS	NITROGEN INTAKE
1-27 INDEXES OF RENAL FUNCTION		●									●			●	●						●	●			●				●																●	
1-28 RENAL CALCULUS FORMATION														●							●		●	●	●				●						●											
1-29 RENAL INFECTION																					●									●					●									●		
1-30 ENERGY METABOLISM	●	●	●	●	●																																									
1-31 CARBOHYDRATE AND FAT METABOLISM		●		●								●	●				●										●																			
1-32 PROTEIN METABOLISM		●	●								●																	●						●												●
1-33 FLUID-ELECTROLYTE BALANCE		●	●			●	●	●	●	●		●		●					●	●		●			●	●	●	●												●						
1-34 MINERAL METABOLISM																●	●	●					●	●							●	●	●													
1-35 BONE DENSITY																●	●	●					●	●								●	●					●								
1-36 MUSCLE MASS AND STRENGTH															●							●																	●	●		●	●			
1-37 ELECTROMYOGRAPHIC EVALUATION															●	●	●	●				●																●	●	●	●	●	●			
1-38 FRACTURE HEALING																●	●	●																	●	●	●	●								
1-39 PRESSURE ATROPHY																●	●	●																	●	●	●	●								

Table A-1 (page 5 of 6)

MEASUREMENT (columns 1–19)

EXPERIMENT TITLE	URINARY 17 - HYDROXY STEROIDS	URINARY ALDOSTERONE	URINARY 17 KETOSTEROIDS	URINARY CATECHOLAMINES	URINARY SEROTONIN	BLOOD PBI	BLOOD - ACTH	SPERM COUNT AND MOTILITY	HISTOLOGICAL EVALUATION	TEMPERATURE, AMBIENT	HUMIDITY	BLOOD FLOW	SKIN TEMPERATURE	CORE TEMPERATURE	BLOOD TSH	AIRFLOW VOLUME	URINE VOLUME	URINE OSMOLALITY	FLUID ELECTROLYTES
1-40 ENDOCRINE FUNCTION, STRESS PHYSIOLOGY	●	●	●	●	●	●	●	●	●								●	●	●
1-41 THERMAL REGULATION						●				●	●	●	●	●	●	●			●
1-42 ADRENAL AND PARATHYROID FUNCTION	●	●	●	●					●								●	●	●
1-43 GONAD HISTOPATHOLOGICAL EVALUATION								●	●										
1-44 LEUKOCYTE REPLICATION																			
1-45 ERYTHROCYTE DYNAMICS																			
1-46 LEUKOCYTE DYNAMICS																			
1-47 PLATELET DYNAMICS																			
1-48 HEMOSTASIS																			
1-49 LEUKOCYTE MOBILIZATION																			
1-50 MAXIMUM RATE OF ERYTHROCYTE PRODUCTION																			
1-51 WOUND HEALING																			

MEASUREMENT (columns 20–38)

EXPERIMENT TITLE	EXPIRED AIR pO_2, CO_2	BLEEDING TIME	BLOOD/HEMATOCRIT	WBC COUNT, TOTAL	WBC COUNT, DIFFERENTIAL	WBC MOTILITY	RBC MASS	RBC COUNT	RBC SURVIVAL TIME	PLASMA VOLUME	RETICULOCYTE COUNT	HEMOGLOBIN	CELL MORPHOLOGY	CYTOGENETIC EXAMINATION	PLATELET COUNT	BLOOD-CLOTTING TIME	RBC FRAGILITY	CLOT RETRACTION	PHAGOCYTOSIS
1-40 ENDOCRINE FUNCTION, STRESS PHYSIOLOGY	●																		
1-41 THERMAL REGULATION	●																		
1-42 ADRENAL AND PARATHYROID FUNCTION																			
1-43 GONAD HISTOPATHOLOGICAL EVALUATION																			
1-44 LEUKOCYTE REPLICATION				●	●								●	●					
1-45 ERYTHROCYTE DYNAMICS			●				●	●	●	●	●	●	●				●		
1-46 LEUKOCYTE DYNAMICS				●	●	●							●						●
1-47 PLATELET DYNAMICS													●		●	●		●	
1-48 HEMOSTASIS		●													●	●		●	
1-49 LEUKOCYTE MOBILIZATION				●	●	●							●						●
1-50 MAXIMUM RATE OF ERYTHROCYTE PRODUCTION			●				●	●	●		●		●						
1-51 WOUND HEALING				●	●														

Table A-1 (page 6 of 6)

EXPERIMENT TITLE	MEASUREMENT: BACTERIAL QUANTITY	BACTERIAL IDENTIFICATION	FUNGUS-QUANTITY	SAMPLE COLLECTION
1-52 EVALUATION OF SURFACES	●	●	●	
1-53 CREW MEMBER EVALUATIONS*	●	●	●	●
1-54 AIR SAMPLING	●	●	●	●
1-55 IMMUNOLOGICAL EVALUATION				●

*SUGGESTED STORAGE OF SAMPLE FOR VIROLOGY. NO ON-BOARD DETERMINATIONS.

Table A-2 (page 1 of 6)
BIOMEDICAL RESEARCH EQUIPMENT

EXPERIMENT TITLE	ELECTROENCEPHALOGRAPH	CAMERAS	NYSTAGMOGRAPHIC GOGGLES	VISION TEST TARGET	PHOROPTER	TILTING MOTION CHAIR	SHORT RADIUS HUMAN CENTRIFUGE	OSCILLOSCOPE AND RECORDER	ANIMAL RESTRAINT	TEMPERATURE RECORDER
1-1 HEAD MOVEMENT DURING ROTATION	●	●	●	●	●	●	●			
1-2 OTOLITHS AND SEMICIRCULAR CANALS	●	●	●	●	●	●	●			
1-3 ALTERED DAY NIGHT CYCLES ON LITTERS (RATS) AND EEG (CATS)	●	●								●
1-4 RESTING DISCHARGE OF VESTIBULAR RECEPTOR CELLS IN PRIMATES	●							●	●	

Table A-2 (page 2 of 6)

EXPERIMENT TITLE	ARTERIAL PRESSURE RECORDER	ELECTROCARDIOGRAPH	BALLISTOCARDIOGRAPHY	CARDIAC OUTPUT COMPUTER	PHONOCARDIOGRAPH	CARDIOTACHOMETER	EXPIRATORY GAS ANALYZER	SPIROMETER	PLETHYSMOGRAPH	ERGOMETER	CAROTID CUFF	PLETHYSMOGRAPHIC GOGGLES	VISION TEST TARGET	RADIOACTIVE TRACERS	LIMB PRESSURE CUFFS	EXPIRATORY RESISTANCE DEVICE	SCINTILLATION COUNTER/SCALER	CLINICAL CENTRIFUGE	BODY VOLUMETER	MASS MEASUREMENT DEVICES	ELECTROENCEPHALOGRAPH	LBNP EQUIPMENT	TEMPERATURE RECORDER	SHORT RADIUS HUMAN CENTRIFUGE	RECORDING MANOMETER	OSCILLOSCOPE AND RECORDER	SPECTROPHOTOMETER	URINE COLLECTION, MEAS'T UNIT	FROZEN STORAGE UNIT	BIOCHEMISTRY ANALYSIS EQUIPMENT	CAMERAS
1-5 CIRCULATORY RESPONSES	●	●		●	●	●				●					●																
1-6 BLOOD DISTRIBUTION EFFECTS ON ARTERIAL PRESSURE CONTROL	●	●				●									●	●												●	●	●	
1-7 VENOUS COMPLIANCE CHANGES						●			●																						
1-8 CARDIAC DYNAMICS	●	●	●	●	●																										
1-9 INTRAOCULAR BLOOD PRESSURE	●											●	●																		
1-10 LOWER BODY NEGATIVE PRESSURE DEVICE	●	●		●		●		●	●												●	●									
1-11 ON-BOARD CENTRIFUGE	●	●		●		●	●	●	●											●	●		●	●							●
1-12 OCCLUSIVE CUFF RESPONSE	●	●		●		●	●	●	●						●								●								
1-13 CAROTID SINUS SENSITIVITY	●	●		●		●		●	●		●																				
1-14 ARTERIOLAR REACTIVITY	●								●						●																
1-15 BLOOD AND BODY FLUID VOLUME CHANGES														●			●	●	●	●								●		●	
1-16 PRIMATE CAROTID BARORECEPTOR ACTIVITY	●	●				●	●							●	●		●	●		●			●		●	●					
1-17 DIRECT CARDIAC OUTPUT VERSUS INDIRECT METHODS	●	●	●	●		●	●	●										●		●			●		●	●	●				
1-18 RESPONSE TO SHOCK THERAPY	●	●		●		●	●	●							●	●		●		●			●		●	●	●				

Table A-2 (page 3 of 6)

EXPERIMENT TITLE	SPIROMETER	OXIMETER	EXPIRATORY GAS ANALYZER	pH METER	SPECIFIC ION ELECTRODES	TISSUE FIXATIVES	NEBULIZER CHAMBER	TEMPERATURE RECORDER	AEROSOL PARTICLE ANALYZER	IMBIBED TRANSMITTER	RUBBER BALLOON	RADIOACTIVE TRACERS	SCINTILLATION COUNTER/SCALER	STOMACH TUBE	TRANSDUCER AND RECORDER	BLOOD GAS ANALYZER	DISSECTING MICROSCOPE	HEMOCYTOMETER	BACTERIOLOGY EQUIPMENT	CAMERAS	MASS MEASUREMENT DEVICES	URINE AND FECES STORAGE UNIT	EXPIRATORY GAS ANALYZER
1-19 PULMONARY MECHANICS	●														●								●
1-20 CONTROL OF RESPIRATION	●	●	●	●	●											●							
1-21 BLOOD GAS EXCHANGE	●	●	●	●	●											●							
1-22 LUNG CLEANSING IN RATS						●	●	●	●								●	●		●			
1-23 INDUCED PULMONARY INFECTIONS IN MICE						●	●	●											●	●			●
1-24 RECOVERY RATE FROM NONINFECTIOUS LUNG TRAUMA IN RATS						●	●	●												●			
1-25 INTESTINAL ABSORPTION												●	●								●	●	
1-26 MOTILITY AND pH				●						●	●			●	●								

Table A-2 (page 4 of 6)

EXPERIMENT TITLE	BODY VOLUMETER	EXPIRATORY GAS ANALYZER	RADIOACTIVE TRACERS	SCINTILLATION COUNTER/SCALER	SPECTROPHOTOMETER	ELECTROPHORESIS APPARATUS	SPECIFIC ION ELECTRODES	pH METER	OSMOMETER	REFRIGERATION UNIT	URINE AND FECES STORAGE UNITS	MASS MEASUREMENT DEVICES	TEMPERATURE RECORDER	ERGOMETER	TISSUE FIXATIVES	NITROGEN ANALYZER	ELECTROMYOGRAPH AND RECORDER	MUSCLE DYNAMOMETER	URINE COLLECTION EQUIPMENT	BIOCHEMISTRY ANALYSIS EQUIPMENT	FECAL COLLECTION EQUIPMENT	BONE DENSITIOMETER	BACTERIOLOGY EQUIPMENT
1-27 INDICES OF RENAL FUNCTION					●		●	●	●			●											
1-28 RENAL CALCULUS FORMATION					●		●	●	●						●				●				
1-29 RENAL INFECTION									●						●								●
1-30 ENERGY METABOLISM	●	●										●	●	●									
1-31 CARBOHYDRATE AND FAT METABOLISM		●					●					●								●			
1-32 PROTEIN METABOLISM	●										●	●				●			●				
1-33 FLUID-ELECTROLYTE BALANCE	●	●	●	●	●	●	●	●	●	●		●		●		●				●			
1-34 MINERAL METABOLISM					●						●			●					●	●	●		
1-35 BONE DENSITY											●								●	●	●	●	
1-36 MUSCLE MASS AND STRENGTH														●				●	●	●			
1-37 ELECTROMYOGRAPHIC EVALUATION														●			●	●		●		●	
1-38 FRACTURE HEALING			●	●											●					●		●	
1-39 PRESSURE ATROPHY.			●	●											●					●		●	

Column group heading: EQUIPMENT

Table A-2 (page 5 of 6)

EXPERIMENT TITLE	SPECIFIC HORMONE ASSAY EQUIPMENT	TEMPERATURE RECORDER	SPECIFIC ION ELECTRODES	EXPIRATORY GAS ANALYZER	OSMOMETER	TISSUE FIXATIVES	URINE STORAGE	REFRIGERATION UNIT	FROZEN STORAGE UNIT	SPECTROPHOTOMETER	ERGOMETER	HUMIDITY RECORDER	GAS FLOWMETER	RADIOACTIVE TRACERS	SCINTILLATION COUNTER/SCALER	CYTOLOGY STAINS	PHOTOMICROGRAPHIC APPARATUS	INCUBATOR (37ºC)	HEMOGLOBINOMETER	BIOCHEMISTRY ANALYSIS EQUIPMENT	CONSTANTAN/SILVER THERMOCOUPLE	MICROSCOPE	HEMOCYTOMETER	RADIATION DOSIMETER	CLINICAL CENTRIFUGE	CAMERAS
1-40 ENDOCRINE FUNCTION, STRESS PHYSIOLOGY	●	●	●	●	●	●	●	●	●	●	●									●						
1-41 THERMAL REGULATION	●	●	●	●						●	●	●	●								●					
1-42 ADRENAL AND PARATHYROID FUNCTION	●					●	●	●	●																	
1-43 GONAD HISTOPATHOLOGICAL EVALUATION						●																●	●	●		
1-44 LEUKOCYTE REPLICATION																●	●									
1-45 ERYTHROCYTE DYNAMICS														●	●	●			●							
1-46 LEUKOCYTE DYNAMICS																●	●	●				●	●			
1-47 PLATELET DYNAMICS																●	●	●								
1-48 HEMOSTASIS																●	●	●								
1-49 LEUKOCYTE MOBILIZATION																●	●									
1-50 MAXIMUM RATE OF ERYTHROCYTE PRODUCTION														●	●	●	●		●						●	
1-51 WOUND HEALING																						●	●			●

The 26 equipment columns are grouped under the heading EQUIPMENT.

Table A-2 (page 6 of 6)

	EXPERIMENT TITLE	INCUBATOR (37°C)	SELECTED GROWTH MEDIA	REFRIGERATED STORAGE	FROZEN STORAGE UNIT	REYNIERS SAMPLER	ANDERSON SAMPLER	AUTOCLAVE	LYOPHILIZATION APPARATUS	PHOTOMICROGRAPHY APPARATUS	COLONY COUNTER
		EQUIPMENT									
1-52	EVALUATION OF SURFACES	●	●	●	●			●	●	●	●
1-53	CREW MEMBER EVALUATIONS*	●	●	●	●			●	●	●	●
1-54	AIR SAMPLING	●	●	●	●	●	●	●	●	●	●
1-55	IMMUNOLOGICAL EVALUATION				●						

*VIROLOGY SAMPLES STORED FOR GROUND ANALYSIS.

Table A-3
BEHAVIORAL EXPERIMENTS AND MEASUREMENTS

EXPERIMENT NO.	EXPERIMENT TITLE	VOICE RECORD	EVENT RECORD	TIME	SUBJECTIVE OPINION	ENERGY EXPENDITURE	FOOD/WATER CONSUMPTION	CONTROL-DISPLAY DYNAMICS	BODY ACCELERATION	BODY POSITION	DEXTERITY	FORCE PRODUCTION	LOCOMOTION	MANIPULATION	MASS MOTION/ACCELERATION	ATTENTION	AUDITORY DETECTION/DISCRIMINATION	BRIGHTNESS DETECTION/DISCRIMINATION	COLOR DETECTION/DISCRIMINATION	COMPLEX SEQUENCE	CRITICAL FLICKER FUSION
2-1	ACCESSIBILITY	●	●	●		●					●		●								
2-2	RESTRAINT AND FINE-FORCE GENERATION	●	●	●	●	●						●		●							
2-3	RESTRAINT AND GROSS-FORCE GENERATION	●	●	●	●	●					●	●	●								
2-4	PERSONNEL TRANSLATION	●	●	●	●	●					●		●								
2-5	MASS TRANSLATION	●	●	●	●	●					●		●		●						
2-6	ORIENTATION, STABILITY, AND RESTRAINT	●	●	●		●			●	●											
2-7	COMMUNICATIONS AND RECORDING	●	●	●	●			●			●			●							
2-8	MONITORING AND OBSERVATION	●	●	●	●																
2-9	HIGHER MENTAL FUNCTION	●	●	●	●											●					
2-10	VISUAL FUNCTION	●	●		●													●	●		●
2-11	AUDITORY FUNCTION	●	●	●													●				
2-12	SOMESTHETIC FUNCTION	●	●																		
2-13	ORIENTATION SENSES	●	●	●	●					●											
2-14	CHEMICAL SENSE FUNCTION	●	●	●																	
2-15	PSYCHOMOTOR FUNCTIONS	●	●	●	●	●								●						●	
2-16	FOOD MANAGEMENT	●	●	●	●		●				●			●							
2-17	WATER MANAGEMENT	●	●	●	●		●				●			●							
2-18	WASTE MANAGEMENT	●	●	●	●						●		●								
2-19	HYGIENE SYSTEM	●	●	●	●	●					●			●							
2-20	VOLUME AND LAYOUT	●	●	●	●						●		●								
2-21	CLOTHING	●	●	●	●	●				●	●		●								
2-22	INTERIOR DESIGN	●	●		●																
2-23	RECREATION	●	●	●	●																
2-24	INTRAPERSONAL FACTORS	●	●		●																
2-25	INTERPERSONAL FACTORS	●	●		●																
2-26	WORK/REST/SLEEP CYCLES	●	●	●	●						●			●		●					●

EXPERIMENT NO.	EXPERIMENT TITLE	EYE MOVEMENT	FORM DISCRIMINATION	JUDGMENT	LIGHT AND DARK ADAPTION	MEMORY	NOISE SENSITIVITY	PROBLEM SOLVING	REACTION TIME	TRACKING	VERIDICALITY	VIGILANCE	VISUAL ACUITY	ELECTROENCEPHALOGRAPHY	GALVANIC SKIN RESPONSE	SKIN SENSITIVITY	SMELL SENSITIVITY	TASTE SENSITIVITY	AREA/COMPARTMENT UTILIZATION FREQUENCY	EMOTIONAL ASSESSMENT	DEPTH PERCEPTION	MOOD ASSESSMENT
2-1	ACCESSIBILITY																					
2-2	RESTRAINT AND FINE-FORCE GENERATION																					
2-3	RESTRAINT AND GROSS-FORCE GENERATION																					
2-4	PERSONNEL TRANSLATION																					
2-5	MASS TRANSLATION																					
2-6	ORIENTATION, STABILITY, AND RESTRAINT																					
2-7	COMMUNICATIONS AND RECORDING																					
2-8	MONITORING AND OBSERVATION								●													
2-9	HIGHER MENTAL FUNCTION			●		●		●				●										
2-10	VISUAL FUNCTION	●	●		●						●		●								●	
2-11	AUDITORY FUNCTION						●															
2-12	SOMESTHETIC FUNCTION															●						
2-13	ORIENTATION SENSES																					
2-14	CHEMICAL SENSE FUNCTION																●	●				
2-15	PSYCHOMOTOR FUNCTIONS								●	●												
2-16	FOOD MANAGEMENT																					
2-17	WATER MANAGEMENT																					
2-18	WASTE MANAGEMENT																					
2-19	HYGIENE SYSTEM																					
2-20	VOLUME AND LAYOUT																		●			
2-21	CLOTHING																					
2-22	INTERIOR DESIGN																					●
2-23	RECREATION																		●			
2-24	INTRAPERSONAL FACTORS													●	●					●		
2-25	INTERPERSONAL FACTORS																			●		
2-26	WORK/REST/SLEEP CYCLES			●		●		●	●	●		●		●								

Table A-4
BEHAVIORAL RESEARCH EQUIPMENT

EXPERIMENT TITLE	AUDIO RECORDER	CAMERAS AND LIGHTS	TIMER	LOG BOOK	METABOLIC MONITOR	QUESTIONNAIRES	PAPER AND PEN TESTS	TAPE MEASURE	BACKGROUND GRID	TOOLS	RESTRAINTS	LOCOMOTION AIDS	EQUIPMENT ATTACHMENT DEVICES	TORQUE FORCE APPARATUS	STANDARD DEXTERITY APPARATUS	ERGOMETER	ACCELEROMETERS AND RECORDS	CRT AND OTHER DISPLAYS	DISPLAY ASSOCIATED CONTROLS	ANALOG RECORDER	ORTHORATER	LIGHT SOURCE	CFF SOURCE	VERIDICALITY TESTER	COLOR PLATES	PURE TONE SOURCE	NOISE AND VIBRATION SOURCE	GSR SENSORS/RECORDER	EEG SENSORS/RECORDER	ELECTRO-OCULOGRAPH AND RECORDER	TUNING FORK	COTTON TUFT AND NEEDLES	OLFACTORY AEROSOLS	GUSTATORY SOLUTIONS	MICROSYRINGES	DIONIZED STERILE WATER
2-1 ACCESSIBILITY	●	●	●	●	●			●	●		●	●																								
2-2 RESTRAINT AND FINE-FORCE GENERATION	●	●	●	●	●	●				●	●			●		●																				
2-3 RESTRAINT AND GROSS-FORCE GENERATION	●	●	●	●	●	●				●	●			●		●																				
2-4 PERSONNEL TRANSLATION	●	●	●	●	●	●			●		●	●																								
2-5 MASS TRANSLATION	●	●	●	●	●	●			●		●	●					●																			
2-6 ORIENTATION, STABILITY, AND RESTRAINT	●	●	●	●	●						●	●					●																			
2-7 COMMUNICATIONS AND RECORDING	●	●	●	●		●	●											●	●																	
2-8 MONITORING AND OBSERVATION	●	●	●	●		●												●	●																	
2-9 HIGHER MENTAL FUNCTION	●			●		●	●											●	●	●																
2-10 VISUAL FUNCTION	●	●	●	●		●															●	●	●	●	●					●						
2-11 AUDITORY FUNCTION	●		●	●																						●	●									
2-12 SOMESTHETIC FUNCTION	●			●																											●	●				
2-13 ORIENTATION SENSES	●	●	●	●		●																														
2-14 CHEMICAL SENSE FUNCTION	●		●	●																													●	●	●	●
2-15 PSYCHOMOTOR FUNCTIONS	●	●	●	●	●						●				●			●	●																	
2-16 FOOD MANAGEMENT	●	●	●	●		●																														
2-17 WATER MANAGEMENT	●	●	●	●		●																														
2-18 WASTE MANAGEMENT	●	●	●	●		●																														
2-19 HYGIENE SYSTEM	●	●	●	●	●	●																														
2-20 VOLUME AND LAYOUT	●	●	●	●		●																														
2-21 CLOTHING	●	●	●	●	●	●																														
2-22 INTERIOR DESIGN	●			●		●	●																													
2-23 RECREATION	●	●	●	●		●																														
2-24 INTRAPERSONAL FACTORS	●			●		●	●																					●	●							
2-25 INTERPERSONAL FACTORS	●			●		●	●																													
2-26 WORK/REST/SLEEP CYCLES	●		●	●	●	●										●													●							

Table A-5
BIOSCIENCE EXPERIMENTS AND MEASUREMENTS

MEASUREMENT

EXPERIMENT TITLE	HEART RATE AND/OR ELECTROCARDIOGRAPHY	RESPIRATORY RATE	ELECTROMYOGRAPHY	GALVANIC SKIN RESPONSE	ELECTRO-OCULOGRAPHY	METABOLIC RATE	BODY TEMPERATURE/HEAT BALANCE	FOOD (AND WATER)/INTAKE/WASTE OUTPUT	URINALYSIS	FECAL ANALYSIS	BODY WATER/EXTRA-CELLULAR FLUID	TOTAL BLOOD VOLUME	TOTAL RED CELL MASS	TOTAL PLASMA VOLUME	TOTAL BODY MASS	TOTAL MUSCLE/MASS NITROGEN BALANCE	SKELETAL MASS	CALCIUM/TOTAL MINERAL BALANCE	ELECTROLYTE BALANCE/PH	ORGAN MASS	ORGAN HISTOLOGY AND HISTOCHEMISTRY	CYTOLOGY AND CYTOCHEMISTRY (INCL. BLOOD)	BLOOD PRESSURES	INTRACRANIAL PRESSURE/BRAIN TEMPERATURE
3-1 PRIMATE BEHAVIOR	●	●	●	●	●	●	●	●	●						●	●		●	●				●	●
3-2 MOUSE BEHAVIOR																								
3-3 FISH BEHAVIOR																								
3-4 DAPHNIA BEHAVIOR																								
3-5 COCKROACH BEHAVIOR																								
3-6 DROSOPHILA BEHAVIOR																								
3-7 ANT BEHAVIOR																								
3-8 DINOFLAGELLATE BEHAVIOR																						●		
3-9 PRIMATE BIORHYTHMS																								
3-10 MOUSE BIORHYTHMS							●																	
3-11 COCKROACH BIORHYTHMS																					●			
3-12 DROSOPHILA BIORHYTHMS																								
3-13 CAPSICUM BIORHYTHMS																			●					
3-14 AVENA BIORHYTHMS																								
3-15 FISH GENETICS																								
3-16 DROSOPHILA GENETICS																					●			
3-17 AMOEBA GENETICS																						●		
3-18 E. COLI GENETICS						●																●		
3-19 E. COLI (T4) LYSOGENY GENETICS																						●		
3-20 NEUROSPORA GENETICS																						●		
3-21 FISH GEOSENSITIVITY																								
3-22 DROSOPHILA GEOSENSITIVITY																								
3-23 CAPSICUM GEOSENSITIVITY																								
3-24 AVENA GEOSENSITIVITY																								
3-25 HUMAN CELL GEOSENSITIVITY																						●		
3-26 PRIMATE HEMODYNAMICS	●	●				●	●	●					●	●	●	●		●	●				●	
3-27 PRIMATE METABOLISM	●	●				●	●	●	●		●	●	●	●	●	●		●	●				●	
3-28 MOUSE METABOLISM	●	●				●	●	●	●	●	●				●	●	●	●	●	●				
3-29 DAPHNIA METABOLISM						●										●		●	●		●			
3-30 DROSOPHILA METABOLISM						●																		
3-31 CROWN GALL METABOLISM						●																●		
3-32 AVENA METABOLISM						●															●	●		
3-33 DINOFLAGELLATE METABOLISM						●																●		
3-34 NEUROSPORA METABOLISM						●													●	●		●		
3-35 FROG EGGS MORPHOGENESIS																					●			
3-36 FISH MORPHOGENESIS																				●	●			
3-37 DAPHNIA MORPHOGENESIS																			●		●			
3-38 FLATWORM MORPHOGENESIS																					●			
3-39 DROSOPHILA MORPHOGENESIS																					●			
3-40 CROWN GALL MORPHOGENESIS																					●	●		
3-41 AVENA MORPHOGENESIS																								
3-42 AMARANTHUS MORPHOGENESIS																								
3-43 AMOEBA MORPHOGENESIS																								
3-44 BROMELIAD MORPHOGENESIS								●																
3-45 CROWN GALL PARASITISM																								
3-46 MOUSE LEUKEMIA															●					●				
3-47 AMOEBA PARASITISM										●											●	●		
3-48 HUMAN CELL REPRODUCTION																					●	●		
3-49 PRIMATE RADIATION	●	●				●	●	●	●		●		●	●	●	●	●	●	●	●	●		●	
3-50 FLATWORM REGENERATION																					●			

EXPERIMENT TITLE	BLOOD FLOW RATES	CARDIAC OUTPUT	TOTAL HEMOGLOBIN	TOTAL PLASMA PROTEIN	TOTAL BODY FAT	MICROCIRCULATION FLOW	ORIENTATION	ERGOMETRIC/BEHAVIORAL PERFORMANCE	GROSS BODY ACTIVITIES	LIMB DECONDITIONING	GROWTH AND DEVELOPMENT	REPRODUCTIVE BEHAVIOR	RADIATION DOSAGES	BONE DENSITY	CELL DIVISION/CHROMOSOME ANALYSES	ENZYME/OTHER METABOLITE ASSAYS	BIOLOGICAL RHYTHMS	PHOTOSYNTHESIS/LUMINESCENCE	GERMINATION AND DEVELOPMENT	MUTATION RATES/RNA-DNA KINETICS	TROPISMS	VISUAL COUNTING	AMBIENT TEMPERATURE/PRESSURE
3-1 PRIMATE BEHAVIOR	●						●	●	●					●									
3-2 MOUSE BEHAVIOR							●	●	●		●	●											
3-3 FISH BEHAVIOR								●													●		
3-4 DAPHNIA BEHAVIOR							●	●	●		●	●										●	
3-5 COCKROACH BEHAVIOR							●	●	●			●											
3-6 DROSOPHILA BEHAVIOR							●	●	●			●											
3-7 ANT BEHAVIOR							●	●	●			●											
3-8 DINOFLAGELLATE BEHAVIOR							●								●		●	●					
3-9 PRIMATE BIORHYTHMS						●		●	●								●						
3-10 MOUSE BIORHYTHMS							●		●														●
3-11 COCKROACH BIORHYTHMS												●					●						
3-12 DROSOPHILA BIORHYTHMS																	●						●
3-13 CAPSICUM BIORHYTHMS							●						●				●	●	●		●		
3-14 AVENA BIORHYTHMS													●			●	●		●		●		
3-15 FISH GENETICS							●	●			●										●		
3-16 DROSOPHILA GENETICS													●		●	●				●		●	
3-17 AMOEBA GENETICS											●	●	●		●					●			
3-18 E. COLI GENETICS											●		●		●	●				●		●	
3-19 E. COLI (T4) LYSOGENY GENETICS											●		●		●	●				●			
3-20 NEUROSPORA GENETICS											●	●	●		●		●		●	●		●	
3-21 FISH GEOSENSITIVITY							●		●														
3-22 DROSOPHILA GEOSENSITIVITY							●	●	●												●		
3-23 CAPSICUM GEOSENSITIVITY							●						●			●					●		
3-24 AVENA GEOSENSITIVITY							●									●					●		
3-25 HUMAN CELL GEOSENSITIVITY							●				●				●	●							
3-26 PRIMATE HEMODYNAMICS		●				●								●									
3-27 PRIMATE METABOLISM		●							●	●				●									
3-28 MOUSE METABOLISM									●					●		●							
3-29 DAPHNIA METABOLISM											●		●										
3-30 DROSOPHILA METABOLISM																●							
3-31 CROWN GALL METABOLISM											●		●		●	●							
3-32 AVENA METABOLISM											●		●			●		●	●				
3-33 DINOFLAGELLATE METABOLISM											●				●	●		●				●	
3-34 NEUROSPORA METABOLISM											●	●	●		●	●			●				
3-35 FROG EGGS MORPHOGENESIS											●				●	●							●
3-36 FISH MORPHOGENESIS											●												
3-37 DAPHNIA MORPHOGENESIS									●		●		●		●							●	●
3-38 FLATWORM MORPHOGENESIS									●		●	●											
3-39 DROSOPHILA MORPHOGENESIS											●												
3-40 CROWN GALL MORPHOGENESIS											●		●		●								
3-41 AVENA MORPHOGENESIS											●								●				
3-42 AMARANTHUS MORPHOGENESIS							●				●								●				
3-43 AMOEBA MORPHOGENESIS									●		●	●	●		●	●							
3-44 BROMELIAD MORPHOGENESIS											●							●			●		
3-45 CROWN GALL PARASITISM											●		●		●		●						
3-46 MOUSE LEUKEMIA				●							●		●		●	●							
3-47 AMOEBA PARASITISM									●		●												
3-48 HUMAN CELL REPRODUCTION											●		●		●	●				●			
3-49 PRIMATE RADIATION		●	●			●							●	●									
3-50 FLATWORM REGENERATION							●		●		●	●	●		●								

Table A-6 (page 1 of 2)
BIOSCIENCE RESEARCH EQUIPMENT

EXPERIMENT TITLE	ANIMAL RESTRAINTS	COMPOUND MICROSCOPE SET	STEREO-DISSECTING MCIROSCOPE	MICROMANIPULATORS	MICROTOME	HISTOLOGY KIT	INFRARED SPECTROPHOTOMETER	UV-VISIBLE SPECTROPHOTOMETER	GAS CHROMATOGRAPH	ELECTROPHORESIS APPARATUS	ELECTROANALYTICAL APPARATUS	CO_2 AND O_2 SENSORS	MASS SPECTROMETER	RECORDER (POTENTIOMETRIC)	CENTRIFUGE (ANALYTIC, REFRIGERATED)	CENTRIFUGE (LOW SPEED)	MASS MEASUREMENT DEVICE (MACRO)	MASS MEASUREMENT DEVICE (MICRO)	ISOTOPE TRACER EQUIPMENT	RADIATION SOURCE	RADIATION SHIELDING	RADIATION DOSIMETER	BONE DENSITOMETER	EXERCISER/ERGOMETER	VETERINARY MEDICAL, DISSECTING, OR NECROPSY KIT	ORGANISM CENTRIFUGE (SMALL)	ORGANISM CENTRIFUGE (LARGE)	CLINOSTAT/CENTRIFUGE	AUTOMATIC PLATE SCANNING COUNTER	AUTOMATIC CELL COUNTER	REFRIGERATOR	FREEZER	LYOPHILIZER	INCUBATOR	AUTOCLAVE	TISSUE CULTURE EQUIPMENT	CAMERAS (TV, CINE, STILL)	IMPLANT TELEMETER RECEIVER	TIMER	ECLOSION RATECOUNTER
3-1 PRIMATE BEHAVIOR	●							●				●		●			●				●		●	●	●		●					●					●			
3-2 MOUSE BEHAVIOR																								●	●	●						●					●			
3-3 FISH BEHAVIOR																									●												●			
3-4 DAPHNIA BEHAVIOR		●	●																						●												●			
3-5 COCKROACH BEHAVIOR																									●												●			
3-6 DROSOPHII A BEHAVIOR			●	●																					●												●			
3-7 ANT BEHAVIOR			●	●																																	●			
3-8 DINOFLAGELLATE BEHAVIOR		●						●						●																							●		●	
3-9 PRIMATE BIORHYTHMS	●		●														●						●	●	●							●					●			
3-10 MOUSE BIORHYTHMS																									●							●						●		
3-11 COCKROACH BIORHYTHMS		●	●	●	●	●																			●												●		●	
3-12 DROSOPHILA BIORHYTHMS																																					●			●
3-13 CAPSICUM BIORHYTHMS								●			●										●	●										●					●			
3-14 AVENA BIORHYTHMS		●			●	●		●	●										●	●	●	●						●									●			
3-15 FISH GENETICS																									●												●			
3-16 DROSOPHILA GENETICS		●	●	●	●	●													●	●	●	●			●						●	●					●			
3-17 AMOEBA GENETICS		●		●	●	●													●	●	●	●								●							●			
3-18 E. COLI GENETICS		●						●				●			●	●				●	●	●							●	●	●	●	●							
3-19 E. COLI (T_4) LYSOGENY GENETICS		●						●												●	●	●									●			●	●		●			
3-20 NEUROSPORA GENETICS		●	●	●	●	●		●						●						●	●	●				●				●							●			
3-21 FISH GEOSENSITIVITY																									●							●					●			
3-22 DROSOPHILA GEOSENSITIVITY			●	●																					●												●			
3-23 CAPSICUM GEOSENSITIVITY								●													●							●									●			
3-24 AVENA GEOSENSITIVITY																												●									●			
3-25 HUMAN CELL GEOSENSITIVITY			●					●										●	●												●	●					●			
3-26 PRIMATE HEMODYNAMICS	●		●					●			●	●					●	●	●				●	●	●		●					●					●			
3-27 PRIMATE METABOLISM	●		●					●			●	●					●	●	●				●	●	●		●					●					●			
3-28 MOUSE METABOLISM		●					●	●	●	●	●		●	●	●	●	●	●	●				●	●	●							●	●				●		●	
3-29 DAPHNIA METABOLISM		●	●	●	●	●					●								●		●				●															
3-30 DROSOPHILA METABOLISM			●	●								●													●							●	●							
3-31 CROWN GALL METABOLISM		●			●	●						●							●	●	●	●						●								●				
3-32 AVENA METABOLISM		●			●	●		●	●			●		●					●	●	●	●						●								●	●			

Table A-6 (page 2 of 2)

EQUIPMENT

EXPERIMENT TITLE	ANIMAL RESTRAINTS	COMPOUND MICROSCOPE SET	STEREO-DISSENTING MICROSCOPE	MICROMANIPULATORS	MICROTOME	HISTOLOGY KIT	INFRARED SPECTROPHOTOMETER	UV-VISIBLE SPECTROPHOTOMETER	GAS CHROMATOGRAPH	ELECTROPHORESIS APPARATUS	ELECTROANALYTICAL APPARATUS	CO_2 AND O_2 SENSORS	MASS SPECTOMETER	RECORDER (POTENITOMETRIC)	CENTRIFUGE (ANALYTIC, REFRIGERATED)	CENTRIFUGE (LOW SPEED)	MASS MEASUREMENT DEVICE (MACRO)	MASS MEASUREMENT DEVICE (MICRO)	ISOTOPE TRACER EQUIPMENT	RADIATION SOURCE
3-33 DINOFLAGELLATE METABOLISM		●			●	●		●						●					●	
3-34 NEUROSPORA METABOLISM		●	●	●	●			●		●		●						●	●	●
3-35 FROG EGGS MORPHOGENESIS		●																		
3-36 FISH MORPHOGENESIS		●			●	●											●			
3-37 DAPHNIA MORPHOGENESIS		●	●									●								
3-38 FLATWORM MORPHOGENESIS		●	●	●	●	●														
3-39 DROSPHILA MORPHOGENESIS		●	●	●	●	●														
3-40 CROWN GALL MOROPHOGENESIS		●			●	●														●
3-41 AVENA MORPHOGENESIS		●			●	●														
3-42 AMARANTHUS MORPHOGENESIS																				
3-43 AMOEBA, MORPHOGENESIS		●	●	●	●	●														●
-44 BROMELIAD MORPHOGENESIS												●								
3-45 CROWN GALL PARASITISM		●	●		●	●													●	●
3-46 MOUSE LEUKEMIA		●	●	●	●	●	●	●	●	●	●	●	●		●				●	●
3-47 AMOEBA PARASITISM		●	●	●	●	●														
3-48 HUMAN CELL REPRODUCTION		●			●	●														
3-49 PRIMATE RADIATION	●		●		●	●		●			●						●	●	●	●
3-50 FLATWORM REGENERATION		●	●	●	●	●														

EXPERIMENT TITLE	RADIATION SHIELDING	RADIATION DOSIMETER	BONE DESNSITOMETER	EXERCISER/ERGOMETER	VETERINARY MEDICAL, DISSECTING, AND/OR NECROPSY KIT	ORGANISM CENTRIFUGE (SMALL)	ORGANISM CENTRIFUGE (LARGE)	CLINOSTAT/CENTRIFUGE	AUTOMATIC PLATE SCANNING COUNTER	AUTOMATIC CELL COUNTER	REFRIGERATOR	FREEZER	LYOPHILIZER	INCUBATOR	AUTOCLAVE	TISSUE CULTURE EQUIPMENT	CAMERAS (TV, CINE, STILL)	IMPLANT TELEMETRY RECEIVER	TIMER	ECLOSION RATE COUNTER
3-33 DINOFLAGELLATE METABOLISM										●							●			
3-34 NEUROSPORA METABOLISM	●	●				●				●					●		●		●	
3-35 FROG EGGS MORPHOGENESIS											●						●			
3-36 FISH MORPHOGENESIS					●						●	●					●			
3-37 DAPHNIA MORPHOGENESIS		●										●		●			●			
3-38 FLATWORM MORPHOGENESIS					●	●											●		●	
3-39 DROSPHILA MORPHOGENESIS					●							●		●			●			
3-40 CROWN GALL MOROPHOGENESIS	●	●						●								●				
3-41 AVENA MORPHOGENESIS								●									●			
3-42 AMARANTHUS MORPHOGENESIS																	●			
3-43 AMOEBA, MORPHOGENESIS	●	●				●				●	●	●		●			●			
-44 BROMELIAD MORPHOGENESIS																	●			
3-45 CROWN GALL PARASITISM	●	●														●				
3-46 MOUSE LEUKEMIA	●	●			●	●				●		●				●				
3-47 AMOEBA PARASITISM						●					●	●		●			●			
3-48 HUMAN CELL REPRODUCTION	●	●															●			
3-49 PRIMATE RADIATION	●	●	●	●	●		●										●			
3-50 FLATWORM REGENERATION	●	●			●	●						●					●		●	

Table A-7 (page 1 of 2)

LIFE SUPPORT AND PROTECTION SYSTEMS--EXPERIMENTS AND MEASUREMENTS

EXPERIMENT TITLE	MEASUREMENT																																													
	PRESSURE	TEMPERATURE	FLOW RATE	POWER LEVEL	TIME	HUMIDITY	GAS COMPOSITION	PERFORMANCE	RELIABILITY AND MAINTAINABILITY	MICROBIOLOGICAL CONTAMINANTS	CHEMICAL CONTAMINANTS	CONTAMINANT LEVEL	IONIZED RADIATION LEVEL	LEAKAGE	METABOLIC RATE	USE OR DELIVERY RATE	DEBRIS GENERATION	pH AND COD	WATER CONDUCTIVITY	EFFICIENCY OR EFFECTIVENESS	FOOD- AND WATER-USE RATE	WASTE-GENERATION RATE	WATER GENERATION RATE	BIOMEDICAL DATA	HEAT REQUIREMENT	URINE/BLOOD/BIOLOGICAL SAMPLES	ACCELERATION	BOILOFF RATE	HEAT TRANSFER RATE/HEAT BALANCE	CO_2 REMOVAL RATE	CONDENSATION RATE	DEW POINT	VACUUM REQUIREMENT	GAS-GENERATION RATE	DIET	FOOD STORAGE AND PREPARATION	FOOD PALATABILITY	COMFORT CRITERIA	MOBILITY	CENTRIFUGAL FORCE	TOTAL ENERGY	IGNITION TIME	BURNING RATE	VELOCITY/VELOCITY PROFILE	DENSITY	VISUAL OBSERVATION
4-1 LIFE SUPPORT SYSTEM I	●	●	●	●	●	●	●	●	●			●	●	●	●	●	●		●		●	●	●	●																						●
4-2 LIFE SUPPORT SYSTEM II	●	●	●	●	●	●	●	●	●			●	●	●	●	●	●	●	●			●	●	●																						
4-3 RADIOISOTOPE POWER AND EC/LS	●	●	●	●	●	●	●	●	●			●	●	●	●	●	●	●	●			●	●	●	●																					
4-4 LIFE SUPPORT SYSTEMS FOR ANIMALS	●	●	●	●	●	●	●	●	●	●	●	●					●				●	●	●	●		●																				●
4-5 MAINTENANCE AND REPAIR IN ZERO G		●		●	●			●	●					●																																
4-6 TWO-GAS ATMOSPHERE SUPPLY AND CONTROL	●	●	●	●	●		●		●																																					
4-7 FLUID MANAGEMENT AND GAGING	●	●	●	●	●								●			●											●	●																		
4-8 1. ATMOSPHERE SUPPLY METHODS AND COMPONENTS	●	●	●	●	●	●		●						●		●									●																					
2. CHEMICAL STORAGE AND SUPPLY	●	●	●	●	●	●		●	●		●	●													●																					
3. REFRIGERATION/RELIQUEFACTION	●	●	●	●	●															●					●				●																	
4-9 ATMOSPHERE SUPPLY SUBSYSTEM	●	●	●	●	●			●	●					●																																
4-10 ELECTROLYSIS METHODS AND COMPONENTS	●	●	●	●	●		●	●	●		●	●		●																																
4-11 WATER-ELECTROLYSIS SUBSYSTEM	●	●	●	●			●	●	●					●																																
4-12 O_2 RECOVERY METHODS AND COMPONENTS	●	●	●	●	●		●				●	●																																		
4-13 O_2 RECOVERY SUBSYSTEM	●	●	●	●		●	●	●	●		●					●				●			●		●						●															
4-14 CO_2 COLLECTION METHODS AND COMPONENTS	●	●	●	●	●		●	●						●						●					●					●																
4-15 ATMOSPHERE PURIFICATION AND THERMAL CONTROL	●	●	●	●	●	●	●																						●																	
4-16 TRACE CONTAMINANT CONTROL AND MONITORING	●	●	●	●	●	●	●	●	●		●			●						●																										
4-17 BIOLOGICAL CONTROL AND MONITORING OF LIFE-SUPPORT SUBSYSTEMS	●	●	●	●	●	●				●	●			●						●																										
4-18 WATER CONDENSER-SEPARATOR METHODS AND COMPONENTS	●	●	●	●	●	●														●									●		●															
4-19 COOLING METHODS AND COMPONENTS	●	●	●	●		●		●	●											●									●																	
4-20 THERMAL-CONTROL SYSTEM	●	●	●	●				●	●				●							●					●				●																	
4-21 WATER RECOVERY METHODS AND COMPONENTS	●	●	●	●	●			●	●	●	●							●	●				●									●														
4-22 REGENERATIVE WATER MANAGEMENT	●	●	●	●	●			●	●	●	●							●	●				●																							
4-23 POTABILITY MONITORING SYSTEM	●	●	●	●	●				●	●	●							●	●				●									●														
4-24 WASTE MANAGEMENT METHODS AND COMPONENTS	●	●	●	●	●			●	●	●	●									●					●								●													
4-25 COMPLETE WASTE MANAGEMENT	●	●	●	●	●			●	●	●	●						●			●					●								●													
4-26 FOOD STORAGE, PREPARATION, AND FEEDING	●	●		●		●									●	●	●				●	●													●	●	●									
4-27 PROTECTIVE CLOTHING AND SPACE SUIT	●	●	●	●	●	●	●	●					●	●										●														●	●							
4-28 EVA SUIT AND BIOPACK	●	●	●	●	●	●	●	●				●		●	●									●														●	●							
4-29 CARDIOVASCULAR CONDITIONING AND MAINTENANCE		●		●	●										●									●			●													●						
4-30 EQUIPMENT AND PROCEDURES FOR PERSONAL HYGIENE	●	●	●	●				●												●																										●
4-31 FIRE PREVENTION AND SENSING	●	●		●	●	●	●																											●							●	●	●	●		
4-32 LEAK DETECTION	●	●	●	●	●	●								●																																
4-33 FLEXIBLE AIRLOCK	●	●		●	●									●																																
4-34 AIRLOCK GAS CONSERVATION	●	●	●	●	●									●																																

Table A-7 (page 2 of 2)

LIFE SUPPORT AND PROTECTIVE SYSTEMS – EXPERIMENTS AND MEASUREMENTS

MEASUREMENT

EXPERIMENT TITLE	PRESSURE	TEMPERATURE	FLOW RATE	POWER LEVEL	TIME	HUMIDITY	GAS COMPOSITION	PERFORMANCE	RELIABILITY AND MAINTAINABILITY	MICROBIOLOGICAL CONTAMINANTS	CHEMICAL CONTAMINANTS	IONIZED RADIATION LEVEL	LEAKAGE	METABOLIC RATE	USE OR DELIVERY RATE	DEBRIS GENERATION	pH AND COD
4-35 DENSITY PROFILES OF LIQUIDS	●	●			●												
4-36 CAPILLARY STUDIES	●	●	●		●												
4-37 KINETICS/DYNAMICS OF GAS BUBBLES	●	●			●												
4-38 ABSORPTION OF GASES BY LIQUIDS	●	●			●		●										
4-39 GAS-FREE LIQUID MAINTENANCE	●	●	●	●	●	●	●										
4-40 INTERFACE PHENOMENA TESTS	●	●			●												
4-41 VAPOR PURGE OF LIQUID SYSTEMS	●	●													●		
4-42 TRANSPORT OF SOLIDS BY GAS DRAG																	
4-43 SOLID-TO-GAS HEAT TRANSFER IN CABIN AIR HEATING	●	●	●	●	●	●	●										
4-44 GAS-TO-SOLID HEAT TRANSFER IN CABIN AIR COOLING	●	●	●		●	●	●										
4-45 CABIN AIR DISTRIBUTION AND CONTROL	●	●	●	●		●	●										
4-46 THERMAL INSULATION AND SURFACE COATINGS	●	●					●										
4-47 CONVECTIVE HEAT TRANSFER	●	●		●	●												
4-48 SPECTROPHOTOMETRY OF VARIOUS MATERIALS		●			●												
4-49 POOL BOILING	●	●		●													
4-50 CREW COMFORT LEVEL	●	●		●		●	●							●			
4-51 CONDENSING HEAT TRANSFER AND CONDENSATION RATE IN HEAT EXCHANGERS		●	●		●	●											
4-52 TRANSPORT OF LIQUIDS BY GAS DRAG	●	●	●		●	●											
4-53 WATER RECOVERY PRETREATMENT MIXING					●												
4-54 COMPOSITION MIXING AND HEAT TRANSFER	●			●			●			●	●						
4-55 SOLIDS AND FLUIDS COMBUSTION	●	●					●			●	●						
4-56 RETENTION TECHNIQUES FOR LIQUIDS AND SOLIDS DURING EQUIPMENT SERVICING																	
4-57 MANUAL TRANSPORT OF SOLIDS																	
4-58 SPILLAGE RECOVERY AND/OR CLEANUP	●			●													

EXPERIMENT TITLE	WATER CONDUCTIVITY	EFFICIENCY OR EFFECTIVENESS	FOOD AND WATER-USE RATE	WASTE-GENERATION RATE	WATER-GENERATION RATE	BIOMEDICAL MONITORING	HEAT REQUIREMENT	URINE/BLOOD/BIOLOGICAL SAMPLES	ACCELERATION	BOILOFF RATE	HEAT-TRANSFER RATE/HEAT BALANCE	CO_2-REMOVAL RATE	CONDENSATION RATE	DEW POINT	VACUUM REQUIREMENT	GAS-GENERATION RATE	DIET
4-35 DENSITY PROFILES OF LIQUIDS																	
4-36 CAPILLARY STUDIES									●								
4-37 KINETICS/DYNAMICS OF GAS BUBBLES									●		●						
4-38 ABSORPTION OF GASES BY LIQUIDS																	
4-39 GAS-FREE LIQUID MAINTENANCE		●															
4-40 INTERFACE PHENOMENA TESTS																	
4-41 VAPOR PURGE OF LIQUID SYSTEMS		●															
4-42 TRANSPORT OF SOLIDS BY GAS DRAG		●															
4-43 SOLID-TO-GAS HEAT TRANSFER IN CABIN AIR HEATING											●						
4-44 GAS-TO-SOLID HEAT TRANSFER IN CABIN AIR COOLING		●									●						
4-45 CABIN AIR DISTRIBUTION AND CONTROL																	
4-46 THERMAL INSULATION AND SURFACE COATINGS											●						
4-47 CONVECTIVE HEAT TRANSFER										●							
4-48 SPECTROPHOTOMETRY OF VARIOUS MATERIALS		●															
4-49 POOL BOILING											●						
4-50 CREW COMFORT LEVEL																	
4-51 CONDENSING HEAT TRANSFER AND CONDENSATION RATE IN HEAT EXCHANGERS		●														●	
4-52 TRANSPORT OF LIQUIDS BY GAS DRAG									●								
4-53 WATER RECOVERY PRETREATMENT MIXING			●														
4-54 COMPOSITION MIXING AND HEAT TRANSFER											●						
4-55 SOLIDS AND FLUIDS COMBUSTION											●						
4-56 RETENTION TECHNIQUES FOR LIQUIDS AND SOLIDS DURING EQUIPMENT SERVICING																	
4-57 MANUAL TRANSPORT OF SOLIDS																	
4-58 SPILLAGE RECOVERY AND/OR CLEANUP																	

EXPERIMENT TITLE	FOOD STORAGE AND PREPARATION	FOOD PALATABILITY	COMFORT CRITERIA	MOBILITY	CENTRIFUGAL FORCE	TOTAL ENERGY	IGNITION TIME	BURNING RATE	VELOCITY/VELOCITY PROFILE	DENSITY	VISUAL OBSERVATION	WETTING ANGLE	SURFACE TENSION	VISCOSITY	GAS FLOW DISTRIBUTION	ABSORPTION RATE
4-35 DENSITY PROFILES OF LIQUIDS										●						
4-36 CAPILLARY STUDIES											●	●	●	●		
4-37 KINETICS/DYNAMICS OF GAS BUBBLES										●	●		●			
4-38 ABSORPTION OF GASES BY LIQUIDS															●	●
4-39 GAS-FREE LIQUID MAINTENANCE																
4-40 INTERFACE PHENOMENA TESTS										●		●	●			
4-41 VAPOR PURGE OF LIQUID SYSTEMS											●					
4-42 TRANSPORT OF SOLIDS BY GAS DRAG									●	●						
4-43 SOLID-TO-GAS HEAT TRANSFER IN CABIN AIR HEATING									●							
4-44 GAS-TO-SOLID HEAT TRANSFER IN CABIN AIR COOLING									●							
4-45 CABIN AIR DISTRIBUTION AND CONTROL									●		●					
4-46 THERMAL INSULATION AND SURFACE COATINGS									●							
4-47 CONVECTIVE HEAT TRANSFER										●						
4-48 SPECTROPHOTOMETRY OF VARIOUS MATERIALS											●					
4-49 POOL BOILING																
4-50 CREW COMFORT LEVEL			●						●							
4-51 CONDENSING HEAT TRANSFER AND CONDENSATION RATE IN HEAT EXCHANGERS																
4-52 TRANSPORT OF LIQUIDS BY GAS DRAG									●	●						
4-53 WATER RECOVERY PRETREATMENT MIXING																
4-54 COMPOSITION MIXING AND HEAT TRANSFER						●	●		●							
4-55 SOLIDS AND FLUIDS COMBUSTION						●	●	●								
4-56 RETENTION TECHNIQUES FOR LIQUIDS AND SOLIDS DURING EQUIPMENT SERVICING																
4-57 MANUAL TRANSPORT OF SOLIDS																
4-58 SPILLAGE RECOVERY AND/OR CLEANUP																

EXPERIMENT TITLE	LIQUID COMPOSITION	SURFACE SHAPES	DAMPING	MOTION CHARACTERISTICS	FRICTION/DRAG	SURFACE FINISH	ABSORBTIVITY/EMISSIVITY	REFLECTIVE INDEX	VOLTS	AMPS	WATER-REMOVAL RATE	ORIENTATION	CHEMICAL ANALYSIS OF LIQUID	DIFFUSION RATE	ELECTRICAL CONDUCTIVITY	SUBJECTIVE OPINION	THERMAL RADIATION
4-35 DENSITY PROFILES OF LIQUIDS																	
4-36 CAPILLARY STUDIES																	
4-37 KINETICS/DYNAMICS OF GAS BUBBLES																	
4-38 ABSORPTION OF GASES BY LIQUIDS	●																
4-39 GAS-FREE LIQUID MAINTENANCE	●																
4-40 INTERFACE PHENOMENA TESTS		●	●	●								●					
4-41 VAPOR PURGE OF LIQUID SYSTEMS																	
4-42 TRANSPORT OF SOLIDS BY GAS DRAG				●													
4-43 SOLID-TO-GAS HEAT TRANSFER IN CABIN AIR HEATING																	
4-44 GAS-TO-SOLID HEAT TRANSFER IN CABIN AIR COOLING																	
4-45 CABIN AIR DISTRIBUTION AND CONTROL																	
4-46 THERMAL INSULATION AND SURFACE COATINGS						●	●	●									
4-47 CONVECTIVE HEAT TRANSFER									●	●							
4-48 SPECTROPHOTOMETRY OF VARIOUS MATERIALS						●	●	●									
4-49 POOL BOILING																	
4-50 CREW COMFORT LEVEL																	
4-51 CONDENSING HEAT TRANSFER AND CONDENSATION RATE IN HEAT EXCHANGERS											●	●					
4-52 TRANSPORT OF LIQUIDS BY GAS DRAG				●	●												
4-53 WATER RECOVERY PRETREATMENT MIXING													●	●	●		
4-54 COMPOSITION MIXING AND HEAT TRANSFER																	●
4-55 SOLIDS AND FLUIDS COMBUSTION									●	●							●
4-56 RETENTION TECHNIQUES FOR LIQUIDS AND SOLIDS DURING EQUIPMENT SERVICING																●	
4-57 MANUAL TRANSPORT OF SOLIDS																●	
4-58 SPILLAGE RECOVERY AND/OR CLEANUP																●	

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LIFE SUPPORT AND PROTECTIVE SYSTEMS EQUIPMENT

LIFE SUPPORT AND PROTECTIVE SYSTEMS EQUIPMENT

EXPERIMENT TITLE / EQUIPMENT	TEST SPECIMENS	BASELINE EC/LS	PRESSURE SENSOR	TEMPERATURE SENSOR	HUMIDITY SENSOR	DEW POINT METER	FLOW METER	TIMER	CINE/STILL CAMERAS	GAS CHROMATOGRAPH/MASS SPECTROMETER	WORK BENCH AND TOOLS	INFRARED SPECTOPHOTOMETER	LEAK DETECTOR	WATT/VOLT/AMP METER	DOSIMETER	RADIATION LABORATORY	ZERO-G SCALE	SPECIAL CLOTHING/SPACE SUITS	BIOMEDICAL MONITORING EQUIPMENT	METABOLIC MEASURING DEVICE	ELECTRON MICROSCOPE	ILLUMINATION DEVICE	CHEMICAL/MICROBIAL LABORATORY	PUMPS, FANS, AND BLOWERS	ACCELEROMETER/VELOCITY METER
4-1 LIFE SUPPORT SYSTEM I	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●		●			●					
4-2 LIFE SUPPORT SYSTEM II	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●		●			●					
4-3 RADIOISOTOPE POWER AND EC/LS	●	●	●	●	●	●	●	●	●	●	●		●	●	●		●								
4-4 LIFE SUPPORT SYSTEMS FOR ANIMALS	●	●	●	●	●		●	●	●	●	●	●		●		●	●		●				●		
4-5 MAINTENANCE AND REPAIR IN ZERO-G	●	●	●	●	●	●	●	●	●		●		●	●				●				●			

EXPERIMENT TITLE / EQUIPMENT	LIQUID GAGING UNIT	RADIOISOTOPE SHIELDING	GAS COMPRESSOR	ACCUMULATOR/HOLDING TANKS	SPECIAL SPACE RADIATOR	CRYOGENIC SUPPLY	CO_2 SENSOR	ERGOMETER	TETHER/UMBILICALS	EC/LS BACK PACK	IGNITION DEVICE	FIRE DETECTOR	FIRE EXTINGUISHING AGENTS	OPTICAL PYROMETER	ISOTOPE HEATER/POWER SOURCE	TEST FOOD/WATER DISPENSERS	SPECIAL SAMPLING EQUIPMENT	ANIMAL HOUSING	REFRIGERATOR	CREW SPECIAL RESTRAINTS	INTEGRATING REFLECTOMETER	OPTICAL DENSITY SENSOR	TEST CONTAINER WITH BLADDER	PRESSURE CONTROLLER	BUBBLE CHAMBER
4-1 LIFE SUPPORT SYSTEM I																									
4-2 LIFE SUPPORT SYSTEM II															●										
4-3 RADIOISOTOPE POWER AND EC/LS															●										
4-4 LIFE SUPPORT SYSTEMS FOR ANIMALS																●	●	●	●						
4-5 MAINTENANCE AND REPAIR IN ZERO-G																				●					

EXPERIMENT TITLE / EQUIPMENT	PYREX FLASK	PLASTIC SQUEEZE CONTAINER	SHADOWGRAPH	HAND PUMP	HEATING ELEMENT	ORIENTATION DEVICE	DIELECTROPHORESE DEVICE	PHOTO CELL	REFERENCE BACKGROUND GRID	FRICTION-MEASURING DEVICE	GAS LIQUID SEPARATOR	OSCILLOGRAPH	COMFORT SIMULATOR	DIFFUSION COLUMNS	STIRRING UNIT	PRETREATMENT UNIT	DEBRIS DISPOSAL/CONTAINER	CARBON BAG	PLUMBING PURGE UNIT	VACUUM CLEANER	POROUS PLATE WATER SEPARATOR	TRANSPORT CONTAINER	SOLID/GAS SEPARATOR	LIQUID CONTAINER/TANK
4-1 LIFE SUPPORT SYSTEM I																								
4-2 LIFE SUPPORT SYSTEM II																								
4-3 RADIOISOTOPE POWER AND EC/LS																								
4-4 LIFE SUPPORT SYSTEMS FOR ANIMALS																								
4-5 MAINTENANCE AND REPAIR IN ZERO-G																								

Table A-8 (page 2 of 3)

EXPERIMENT TITLE	TEST SPECIMENS	BASELINE EC/LS	PRESSURE SENSOR	TEMPERATURE SENSOR	HUMIDITY SENSOR	DEW-POINT SENSOR	FLOW METER	TIMER	CINE/STILL CAMERAS	GAS CHROMATOGRAPH/MASS SPECTROMETER	WORK BENCH AND TOOLS	INFRARED SPECTROPHOTOMETER	LEAK DETECTOR	WATT/VOLT/AMP METER	DOSIMETER	RADIATION LABORATORY	ZERO-G SCALE	SPECIAL CLOTHING/SPACE SUITS	BIOMEDICAL MONITORING EQUIPMENT	METABOLIC MEASURING DEVICE	ELECTRON MICROSCOPE	ILLUMINATION DEVICE	CHEMICAL/MICROBIAL LABORATORY	PUMPS, FANS, AND BLOWERS	ACCELEROMETER/VELOCITY METER	LIQUID GAGING UNIT	RADIOISOTOPE SHIELDING	GAS COMPRESSOR	ACCUMULATOR/HOLDING TANKS	SPECIAL SPACE RADIATOR	CRYOGENIC SUPPLY	CO_2 SENSOR	ERGOMETER	TETHER/UMBILICALS	EC/LS BACK PACK	IGNITION DEVICE	FIRE DETECTOR	FIRE-EXTINGUISHING AGENTS	OPTICAL PYROMETER	CREW HYGIENE; PROTECTIVE SYSTEM	ISOTOPE HEATER/POWER SOURCE	EMERGENCY BACKUP EC/LS	TEST FOOD/WATER DISPENSERS	SPECIAL SAMPLING EQUIPMENT
4-6 TWO-GAS ATMOSPHERE SUPPLY AND CONTROL	●	●	●	●	●		●	●		●	●			●									●																					
4-7 FLUID MANAGEMENT AND GAGING	●	●	●	●			●	●	●		●			●	●										●		●																	
4-8 1. ATMOSPHERE SUPPLY METHODS AND COMPONENTS	●	●	●	●			●	●					●	●												●																		
2. CHEMICAL STORAGE AND SUPPLY	●	●	●	●	●		●	●		●	●			●									●					●	●															
3. REFRIGERATION/RELIQUEFACTION	●	●	●	●			●	●			●			●															●	●	●													
4-9 ATMOSPHERE SUPPLY SUBSYSTEM	●	●	●	●			●	●		●	●			●																														
4-10 ELECTROLYSIS METHODS AND COMPONENTS	●	●	●	●			●	●		●	●		●	●																														
4-11 WATER ELECTROLYSIS SUBSYSTEM	●	●	●	●			●	●			●			●																														
4-12 O_2 RECOVERY METHODS AND COMPONENTS	●	●	●	●	●		●	●		●	●			●									●	●					●															
4-13 O_2 RECOVERY SUBSYSTEM	●	●	●	●	●		●			●		●		●									●		●																			
4-14 CO_2 COLLECTION METHODS AND COMPONENTS	●	●	●	●	●		●	●		●	●			●																														
4-15 ATMOSPHERE PURIFICATION AND THERMAL CONTROL	●	●	●	●	●	●	●	●		●				●										●					●			●												
4-16 TRACE CONTAMINANT CONTROL AND MONITORING	●	●	●	●	●		●	●		●		●	●	●									●																					
4-17 BIOLOGICAL CONTROL AND MONITORING OF LIFE SUPPORT SUBSYSTEMS	●	●	●	●	●		●	●	●	●			●	●									●	●																				
4-18 WATER CONDENSER-SEPARATOR METHODS AND COMPONENTS	●	●	●	●	●		●	●	●					●										●																				
4-19 COOLING METHODS AND COMPONENTS	●	●	●	●	●		●							●										●																				
4-20 THERMAL CONTROL SYSTEM	●	●	●	●			●				●			●	●	●			●								●														●			
4-21 WATER RECOVERY METHODS AND COMPONENTS	●	●	●	●		●	●	●			●		●	●									●																					
4-22 REGENERATIVE WATER-MANAGEMENT	●	●	●	●			●	●	●				●	●									●																					
4-23 POTABILITY MONITORING SYSTEM	●	●	●	●		●	●	●						●									●																					
4-24 WASTE MANAGEMENT METHODS AND COMPONENTS	●	●	●	●			●	●	●					●									●																					
4-25 COMPLETE WASTE MANAGEMENT	●	●	●	●			●	●	●					●									●																					
4-26 FOOD STORAGE, PREPARATION, AND FEEDING	●	●	●	●	●									●			●		●	●			●										●											
4-27 PROTECTIVE CLOTHING AND SPACE SUIT	●	●	●	●	●		●		●	●	●		●	●					●																	●								
4-28 EVA SUIT AND BIOPACK	●	●	●	●	●		●	●	●	●			●	●					●													●		●										
4-29 CARDIOVASCULAR CONDITIONING AND MAINTENANCE	●		●	●	●			●	●					●					●	●				●	●																			
4-30 EQUIPMENT AND PROCEDURES FOR PERSONAL HYGIENE	●	●	●	●					●		●			●																														
4-31 FIRE PREVENTION AND SENSING	●	●	●	●	●		●	●	●	●				●									●													●	●	●	●					
4-32 LEAK DETECTION	●	●	●	●	●		●	●					●	●																														
4-33 FLEXIBLE AIRLOCK	●	●	●	●			●	●	●				●	●				●																●	●									
4-34 AIRLOCK GAS CONSERVATION	●	●	●	●			●	●						●				●				●							●					●										

Table A-8 (page 3 of 3)

EQUIPMENT

EXPERIMENT TITLE	TEST SPECIMENS	BASELINE EC/LS	PRESSURE SENSOR	TEMPERATURE SENSOR	HUMIDITY SENSOR	DEW-POINT METER	FLOW METER	TIMER	CINE/STILL CAMERAS	GAS CHROMATOGRAPH/MASS SPECTROMETER	WORK BENCH AND TOOLS	INFRARED SPECTROPHOTOMETER	LEAK DETECTOR	WATT/VOLT/AMP METER	DOSIMETER	RADIATION LABORATORY	ZERO-G SCALE	SPECIAL CLOTHING/SPACE SUITS	BIOMEDICAL MONITORING EQUIPMENT	METABOLIC MEASURING DEVICE
4-35 DENSITY PROFILES OF LIQUIDS	●		●	●				●	●											
4-36 CAPILLARY STUDIES	●	●	●	●				●	●											
4-37 KINETICS/DYNAMICS OF GAS BUBBLES	●		●	●				●	●											
4-38 ABSORPTION OF GASES BY LIQUIDS	●		●	●				●												
4-39 GAS-FREE LIQUID MAINTENANCE	●		●	●	●		●	●		●				●						
4-40 INTERFACE PHENOMENA TESTS	●		●					●	●											
4-41 VAPOR PURGE OF LIQUID SYSTEMS	●	●	●	●																
4-42 TRANSPORT OF SOLIDS BY GAS DRAG	●		●	●			●	●	●								●			
4-43 SOLID-TO-GAS HEAT TRANSFER IN CABIN AIR HEATING		●	●	●			●	●		●				●						
4-44 GAS-TO-SOLID HEAT TRANSFER IN CABIN AIR COOLING	●	●	●	●	●		●	●		●										
4-45 CABIN AIR DISTRIBUTION AND CONTROL		●		●	●	●	●			●		●		●						
4-46 THERMAL INSULATION AND SURFACE COATINGS	●		●	●		●	●	●	●		●									
4-47 CONVECTIVE HEAT TRANSFER	●	●	●	●	●				●					●			●			
4-48 SPECTROPHOTOMETRY OF VARIOUS MATERIALS	●	●		●					●		●	●								
4-49 POOL BOILING	●	●	●	●					●					●						
4-50 EFFECT OF WALL TEMPERATURE, VENTILATION RATE, CABIN PRESSURE, GAS COMPOSITION, AND CREW CLOTHING ON COMFORT LEVEL	●	●	●	●	●	●	●	●	●	●				●			●	●	●	●
4-51 CONDENSING HEAT TRANSFER AND CONDENSATION RATE IN HEAT EXCHANGERS	●	●	●	●	●	●	●	●	●					●			●			
4-52 TRANSPORT OF LIQUIDS BY GAS DRAG	●	●	●	●	●	●	●	●	●		●						●			
4-53 WATER RECOVERY PRETREATMENT MIXING	●	●						●												
4-54 COMPOSITION MIXING AND HEAT TRANSFER	●	●	●	●	●			●	●	●		●		●						
4-55 SOLIDS AND FLUIDS COMBUSTION	●	●	●	●	●			●	●	●				●						
4-56 RETENTION TECHNIQUES FOR LIQUIDS AND SOLIDS DURING EQUIPMENT SERVICING	●	●							●											
4-57 MANUAL TRANSPORT OF SOLIDS	●	●							●											
4-58 SPILLAGE RECOVERY AND/OR CLEANUP	●	●	●				●		●		●			●						

EXPERIMENT TITLE	ELECTRON MICROSCOPE	ILLUMINATION DEVICE	CHEMICAL/MICROBIAL LABORATORY	PUMPS, FANS, AND BLOWERS	ACCELEROMETER/VELOCITY METER	LIQUID GASSING UNIT	RADIOISOTOPE SHIELDING	GAS COMPRESSOR	ACCUMULATOR/HOLDING TANKS	SPECIAL SPACE RADIATOR	CRYOGENIC SUPPLY	CO_2 SENSOR	ERGOMETER	TETHERS/UMBILICALS	EC/LS BACK PACK	IGNITION DEVICE	FIRE DETECTOR	FIRE EXTINGUISHING AGENTS	OPTICAL PYROMETER	CREW HYGIENE; PROTECTIVE SYSTEM
4-35 DENSITY PROFILES OF LIQUIDS			●								●									
4-36 CAPILLARY STUDIES					●															
4-37 KINETICS/DYNAMICS OF GAS BUBBLES		●			●															
4-38 ABSORPTION OF GASES BY LIQUIDS			●																	
4-39 GAS-FREE LIQUID MAINTENANCE																				
4-40 INTERFACE PHENOMENA TESTS																				
4-41 VAPOR PURGE OF LIQUID SYSTEMS																				
4-42 TRANSPORT OF SOLIDS BY GAS DRAG																				
4-43 SOLID-TO-GAS HEAT TRANSFER IN CABIN AIR HEATING					●															
4-44 GAS-TO-SOLID HEAT TRANSFER IN CABIN AIR COOLING					●															
4-45 CABIN AIR DISTRIBUTION AND CONTROL			●		●															
4-46 THERMAL INSULATION AND SURFACE COATINGS			●		●															
4-47 CONVECTIVE HEAT TRANSFER		●			●															
4-48 SPECTROPHOTOMETRY OF VARIOUS MATERIALS			●																	
4-49 POOL BOILING																				
4-50 EFFECT OF WALL TEMPERATURE, VENTILATION RATE, CABIN PRESSURE, GAS COMPOSITION, AND CREW CLOTHING ON COMFORT LEVEL					●								●							
4-51 CONDENSING HEAT TRANSFER AND CONDENSATION RATE IN HEAT EXCHANGERS				●																
4-52 TRANSPORT OF LIQUIDS BY GAS DRAG	●				●															
4-53 WATER RECOVERY PRETREATMENT MIXING	●		●																	
4-54 COMPOSITION MIXING AND HEAT TRANSFER				●															●	
4-55 SOLIDS AND FLUIDS COMBUSTION			●													●	●	●	●	
4-56 RETENTION TECHNIQUES FOR LIQUIDS AND SOLIDS DURING EQUIPMENT SERVICING			●																	
4-57 MANUAL TRANSPORT OF SOLIDS																				
4-58 SPILLAGE RECOVERY AND/OR CLEANUP																				

EXPERIMENT TITLE	ISOTOPE HEATER/POWER SOURCE	EMERGENCY BACKUP EC/LS	TEST FOOD/WATER DISPENSERS	SPECIAL SAMPLING EQUIPMENT	ANIMAL HOUSINGS	REFRIGERATOR	CREW SPECIAL RESTRAINTS	INTEGRATING REFLECTOMETER	OPTICAL DENSITY SENSOR	TEST CONTAINER WITH BLADDER	PRESSURE CONTROLLER	BUBBLE CHAMBER	PYREX FLASK	PLASTIC SQUEEZE CONTAINER	SHADOWGRAPH	HAND PUMP	HEATING ELEMENT	ORIENTATION DEVICE	DIELECTROPHORESIS DEVICE	PHOTO CELL
4-35 DENSITY PROFILES OF LIQUIDS										●										
4-36 CAPILLARY STUDIES											●									
4-37 KINETICS/DYNAMICS OF GAS BUBBLES												●	●							
4-38 ABSORPTION OF GASES BY LIQUIDS														●	●	●	●	●		
4-39 GAS-FREE LIQUID MAINTENANCE														●				●		
4-40 INTERFACE PHENOMENA TESTS														●		●		●	●	●
4-41 VAPOR PURGE OF LIQUID SYSTEMS																				
4-42 TRANSPORT OF SOLIDS BY GAS DRAG																				
4-43 SOLID-TO-GAS HEAT TRANSFER IN CABIN AIR HEATING																				
4-44 GAS-TO-SOLID HEAT TRANSFER IN CABIN AIR COOLING																				
4-45 CABIN AIR DISTRIBUTION AND CONTROL																				
4-46 THERMAL INSULATION AND SURFACE COATINGS									●											
4-47 CONVECTIVE HEAT TRANSFER																●				
4-48 SPECTROPHOTOMETRY OF VARIOUS MATERIALS									●											
4-49 POOL BOILING																●				
4-50 EFFECT OF WALL TEMPERATURE, VENTILATION RATE, CABIN PRESSURE, GAS COMPOSITION, AND CREW CLOTHING ON COMFORT LEVEL																				
4-51 CONDENSING HEAT TRANSFER AND CONDENSATION RATE IN HEAT EXCHANGERS																			●	
4-52 TRANSPORT OF LIQUIDS BY GAS DRAG																				
4-53 WATER RECOVERY PRETREATMENT MIXING																				
4-54 COMPOSITION MIXING AND HEAT TRANSFER																				
4-55 SOLIDS AND FLUIDS COMBUSTION																				
4-56 RETENTION TECHNIQUES FOR LIQUIDS AND SOLIDS DURING EQUIPMENT SERVICING																				
4-57 MANUAL TRANSPORT OF SOLIDS																				
4-58 SPILLAGE RECOVERY AND/OR CLEANUP																				

EXPERIMENT TITLE	REFERENCE BACKGROUND DEVICE	FRICTIONLESS BACKGROUND GRID	GAS-LIQUID SEPARATING DEVICE	GAS-LIQUID SEPARATOR	OSCILLOGRAPH	COMFORT SIMULATOR	DIFFUSION COLUMN	STIRRING UNIT	PRETREATMENT UNIT	DEBRIS DISPOSAL/CONTAINER	CARBON BAG	PLUMBING PURGE UNIT	VACUUM CLEANER	POROUS PLATE WATER SEPARATOR	TRANSPORT CONTAINER	SOLID/GAS SEPARATOR	LIQUID CONTAINMENT TANK
4-35 DENSITY PROFILES OF LIQUIDS																	
4-36 CAPILLARY STUDIES																	
4-37 KINETICS/DYNAMICS OF GAS BUBBLES																	
4-38 ABSORPTION OF GASES BY LIQUIDS																	
4-39 GAS-FREE LIQUID MAINTENANCE																	
4-40 INTERFACE PHENOMENA TESTS																	
4-41 VAPOR PURGE OF LIQUID SYSTEMS	●																
4-42 TRANSPORT OF SOLIDS BY GAS DRAG		●	●														●
4-43 SOLID-TO-GAS HEAT TRANSFER IN CABIN AIR HEATING																	
4-44 GAS-TO-SOLID HEAT TRANSFER IN CABIN AIR COOLING																	
4-45 CABIN AIR DISTRIBUTION AND CONTROL																	
4-46 THERMAL INSULATION AND SURFACE COATINGS																	
4-47 CONVECTIVE HEAT TRANSFER					●												
4-48 SPECTROPHOTOMETRY OF VARIOUS MATERIALS																	
4-49 POOL BOILING															●		
4-50 EFFECT OF WALL TEMPERATURE, VENTILATION RATE, CABIN PRESSURE, GAS COMPOSITION, AND CREW CLOTHING ON COMFORT LEVEL						●											
4-51 CONDENSING HEAT TRANSFER AND CONDENSATION RATE IN HEAT EXCHANGERS				●													
4-52 TRANSPORT OF LIQUIDS BY GAS DRAG		●		●													●
4-53 WATER RECOVERY PRETREATMENT MIXING							●	●	●								●
4-54 COMPOSITION MIXING AND HEAT TRANSFER																	
4-55 SOLIDS AND FLUIDS COMBUSTION																	
4-56 RETENTION TECHNIQUES FOR LIQUIDS AND SOLIDS DURING EQUIPMENT SERVICING										●	●	●	●	●			
4-57 MANUAL TRANSPORT OF SOLIDS										●			●		●		
4-58 SPILLAGE RECOVERY AND/OR CLEANUP													●				

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